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# NACA RESEARCH MEMORANDUM

## HIGH-ALTITUDE PERFORMANCE OF AN EXPERIMENTAL TURBOJET COMBUSTOR HAVING VARIABLE PRIMARY-AIR ADMISSION


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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

# HIGH-ALTITUDE PERFORMANCE OF AN EXPERIMENTAL TURBOJET COMBUSTOR HAVING VARIABLE PRIMARY-AIR ADMISSION

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## SUMMARY

As part of a program to determine design criteria for turbojet combustors, 47 experimental tubular designs embodying variable primary-air openings to control the fuel-air ratio in the combustion zone were investigated at simulated high-altitude operating conditions for a representative 5.2-pressure-ratio engine. The performance characteristics considered were combustion efficiency, operating range, and pressure loss.

Variable primary air had a marked effect on combustor performance; in order to maintain maximum combustion efficiency, it was necessary to increase primary-air flow as over-all fuel-air ratio was increased. The best experimental variable-area combustor operated with combustion efficiencies of 89 and 82 percent at cruise engine speed conditions, 56,000 and 70,000 feet of altitude, respectively.

At the cruise condition, the efficiencies of the best experimental model were as much as 25 percent higher than those of a reference production combustor of equal size. At full-rated engine speed, however, the efficiencies of the experimental model were 3 percent lower. Combustion efficiencies greater than 90 percent were not readily achieved and this can probably be attributed to the small size of the combustor.

At the 70,000-foot condition, the operable fuel-air-ratio range of one model of the variable-area combustor was three times the range of the reference production combustor. Use of variable primary air also reduced the detrimental effects of increased temperature rise on pressure loss.

## INTRODUCTION

Design criteria for obtaining high combustion efficiency in turbojet combustors at high-altitude operating conditions are being investigated at the Lewis laboratory. As part of this program, the performance of 47 experimental combustors designed to improve fuel-air mixture conditions within the combustion zone by separate control of the primary air was investigated. Eleven models were chosen as representative and the results are reported herein.

The over-all fuel-air ratio, at which a turbojet combustor must operate, varies with engine speed, altitude, and flight speed. The maximum fuel-air ratio of one current engine is about four times the minimum fuel-air ratio; this range may increase in future turbojet engines if improvements in engine design allow higher turbine-inlet temperature, hence higher fuel-air ratios. At both low and high fuel-air ratios, decreases in performance are frequently observed in turbojet combustors. For example, data presented in reference 1 indicate that at low fuel-air ratios, the use of large fuel nozzles with poor atomization reduced combustion efficiency in an annular turbojet combustor. A fact which may be attributed to an over-lean mixture condition in the combustion zone. 3553
At high fuel-air ratios, small nozzles with fine atomization also reduced the combustion efficiency, which is attributable to an over-rich mixture condition.

One experimental method of continuously controlling the primary-zone fuel-air ratio has been reported in references 2 and 3. The distribution of fuel along the length of the combustor primary zone was varied by means of a series of "staged" injection nozzles.

In the experimental investigation reported herein, the fuel-air ratio in the combustion zone of a turbojet combustor was controlled by varying the primary-air-flow rate. All the primary air was admitted at the front end of the combustor through variable openings. Fuel was introduced into a central primary-air opening and was finely atomized by the air (ref. 4).

The combustors were operated over a wide range of fuel-air ratios at air-flow, pressure, and temperature conditions corresponding to a 5.2-pressure-ratio engine operating at 85-percent rated speed at altitudes of 56,000 and 70,000 feet. In addition, limited data were obtained at two other air flows, one higher and one lower than the cruise air flow at 56,000 feet. Combustion efficiency, pressure-loss, and temperature-profile data were obtained with variable quantities of primary air. The effects of a number of design variables on combustor performance were investigated; these variables included fuel-injector design, air baffles, liner holes, and fuel dams (ref. 5). The 11 models chosen demonstrate the effect of these variables. No attempt was made to evaluate combustor durability, carbon deposition tendencies, or sea-level high-pressure performance.

Also as part of this investigation, the best models of the variable-area combustor are compared with several other experimental and production model combustors.

# APPARATUS

## Combustor Installation

The experimental combustor was installed in a duct connected to the laboratory air-supply and altitude-exhaust facilities as shown in figure 1. Combustor air-flow rates and pressures were regulated by remotely controlled valves located upstream and downstream of the combustor. Combustor-inlet air was heated by an electric heater.

## Instrumentation

Air flows were measured by a concentric-hole, sharp-edged A.S.M.E. orifice installed upstream of the inlet-air control valves and air heater. Fuel flows were measured by calibrated rotameters. Instrumentation for sensing combustor-inlet and -outlet temperatures and pressures was arranged as shown in figure 1. The combustor-inlet-air temperature was sensed by bare-wire, iron-constantan thermocouples (station B, fig. 1); combustor-outlet-air temperature was sensed by single-shielded, chromel-alumel thermocouples (station C, fig. 1). The 16 outlet thermocouples were so connected that individual readings or an instantaneous average temperature reading could be obtained. All thermocouples were connected to self-balancing direct-reading potentiometers. Combustor-inlet and -outlet pressures were sensed by total-pressure tubes (stations A and D, fig. 1) manifolded together at each station to obtain average readings. The combustor-inlet pressure and over-all pressure drop were indicated by an absolute manometer and a U-tube manometer, respectively.

## Combustor

The basic features of the tubular combustor used are shown in figure 2. The air flow to the combustor was channeled into three paths. Two central paths fed primary air into the upstream end of the combustor. The inner primary air passed through a swirler into a swirl chamber and thence to a throat section where the fuel was introduced through radial holes drilled in a fuel disk. The air swirling past these holes atomized the fuel. The outer primary air flowed through an annular passage and converged on the inner primary-air current at the point of entry into the combustion space. Both the inner and outer primary-air flows were varied by axial motion of the throat section, which was attached to a movable sleeve separating the inner and outer primary-air passages. Secondary air flowed in the outermost annulus and completely bypassed the primary combustion zone except for small quantities flowing through louvers for cooling the liner walls. Four large air-entry slots at the downstream end of the liner were provided to obtain a relatively uniform temperature distribution at the combustor outlet.

During operation of the experimental combustor in the duct tests, the primary-air flow was adjusted by the mechanical positioner shown in figure 3. The variation of liner open area, expressed as the ratio of primary open area to total-liner open area, is presented in figure 4 as a function of the crank setting of the mechanical positioner.

Basic dimensions of the experimental combustor are shown in figure 3. The combustor had a maximum cross-sectional area of 0.267 square feet (7 in. diam). The over-all length of the combustor including the inlet diffuser, which contained the area-varying mechanism, was 31.3 inches. The distance from the plane of the fuel injector to the outlet 3553
thermocouples was 27 inches.

A total of 47 experimental combustor models was tested during the investigation. Among the variables studied were: fuel-injection method, primary-air admission, and liner configurations. For the discussion presented herein, a limited number of configurations has been selected to illustrate (1) the best performance obtained, and (2) observed trends in performance with design variables. Drawings of the models chosen are presented in figure 5; the model numbers indicate the order in which the data were obtained.

A variable-area, pintle-type nozzle (fig. 6) was used to inject fuel in combustor models 41 and 46. This nozzle was designed to overcome the poor circumferential fuel distribution normally encountered with pintle-type nozzles without sacrificing the wide-flow range inherent in this type of nozzle. The fuel is channeled into a predetermined number of "streaks" by the flats ground on the surface of the stem (fig. 6). These fuel streaks flow along the shaft, spread out on the tapered pintle, and are atomized in the air as they leave the sharp edge of the pintle. The original model of this nozzle produced the desired spray form (eight uniform streaks) from 7 to 1915 pounds per hour fuel flow, a 270 to 1 flow range (the limit of the test facility). This range was obtained with nozzle pressure drops from 95 to 395 pounds per square inch. For the experimental combustor models 41 and 46, the nozzle pressure drop was adjusted to a lower value and varied from 20 to 70 pounds per square inch over the range of fuel flows investigated (10 to 100 lb/hr).

## Fuel

The fuel used in this investigation was liquid MIL-F-5624B, grade JP-4. Inspection data for the fuel are presented in table I.

## PROCEDURE

Combustion efficiency and combustor pressure-loss data were recorded during operation of each experimental combustor model at one or more of the following combustor-inlet conditions:

| Condition | Total pressure, in. Hg abs | Total temperature, °F | Air-flow rate per unit combustor area, lb/(sec)(sq ft) (a) | Simulated flight altitude in reference engine, ft |
|---|---|---|---|---|
| A | 15 | 268 | 2.78 | 56,000 |
| B | 8 | 268 | 1.48 | 70,000 |
| C | 5 | 268 | .93 | 80,000 |
| D | 15 | 268 | 2.14 | 56,000 |
| E | 15 | 268 | 3.62 | 56,000 |

[a]Based on maximum combustor cross-sectional area, 0.267 sq ft.

These conditions simulate combustor-inlet conditions in a reference turbojet engine with a pressure ratio of 5.2, operating at 85-percent rated speed (cruise condition) and at a flight Mach number of 0.6. Air-flow rates at conditions A, B, and C are representative of current turbojet engines. Air-flow rates approximately 30 percent greater and 23 percent less than the reference conditions are presented by conditions E and D, respectively.

Sufficient data were obtained with each combustor model at several primary-air-flow settings to indicate trends in combustor performance. Data were obtained for most models at conditions A, B, and E; none of the models investigated would operate at condition C. In general, combustor performance was obtained over a range of fuel-air ratios from the lean blow-out point or a minimum temperature rise of approximately 300° F to the rich blow-out point or the maximum safe temperature for the exhaust-gas instrumentation.

Combustion efficiency, defined as the percentage ratio of actual to theoretical increase in enthalpy of gases flowing through the combustor, was computed by the method of reference 6. The average combustor-outlet total-temperature reading was used to calculate the enthalpy of gas at the combustor outlet; indicated temperature readings were not corrected for velocity or radiation effects.

Combustor total-pressure losses are expressed as the dimensionless ratio of the total-pressure loss to the reference velocity pressure (computed from the air flow, maximum combustor cross-sectional area, and combustor-inlet-air density).

Sample combustor-outlet temperature-profile data were taken periodically for each combustor model by recording individual thermocouple readings.

## RESULTS

An investigation was conducted on 47 different variable-area combustor models in an effort to obtain optimum performance characteristics at high-altitude operating conditions. Results obtained with several models, 3553
selected to best illustrate the trends obtained, are presented in figures 7 to 13. Experimental data for the models are presented in table II.

The combustion-efficiency data obtained with combustor model 10 (fig. 5(a)) is plotted in figure 7 to illustrate the effect of varying the primary-air flow. The peak efficiency occurred at successively higher fuel-air ratios as the primary-air flow was increased. At test condition E (fig. 7(a)), the combustor was operated at only one primary-air setting; however, if data were obtained at other settings a similar trend would be expected. The data show that an optimum primary-air flow exists for each over-all fuel-air ratio. Values of primary-zone fuel-air ratio were not measured nor could they be readily computed since neither primary-zone pressure drop nor discharge coefficients of air openings were known.

The use of variable primary-air flow to extend the operable range of fuel-air ratios is illustrated in figure 7(d). Rich blow-out occurred at a fuel-air ratio of approximately 0.026 when the primary-air openings were set at 11 percent of total-liner hole area. By increasing the primary-air openings to 19 percent of total open area, combustion was maintained at a fuel-air ratio of 0.038.

### Effect of Fuel Injector Design

Several of the 47 models investigated incorporated different methods of introducing the fuel. The effect of two fuel-introduction variables on performance are described in the following paragraphs.

Number of holes in fuel disk. - The combustion efficiencies of the combustors having a different number of holes in the fuel-injection disk are presented in figure 8. In figures 8 to 11, only those data obtained with primary-air-flow settings resulting in the highest efficiencies are presented in order to simplify the comparisons. At the milder test conditions E and A (figs. 8(a) and (b)), the number and size of holes in the fuel disk had an almost negligible effect on the performance; however, at test condition B (fig. 8(c)), there is evidence of increase in efficiency when fewer fuel-introduction holes are used. Preliminary data (not shown in fig. 8) indicated that size of fuel holes was relatively unimportant.

Air against mechanical atomization. - The combustion efficiencies of three models having mechanical atomizers installed and one model using air atomization (model 26) are compared in figure 9. In general, all the mechanical spray-nozzle models were characterized by a narrow operating range, even when the primary-air flow was varied. The small fixed-area nozzle (model 34) produced slightly higher efficiencies at low fuel-air ratios at test condition E (fig. 9(a)) and at the high and low ends of the fuel-air-ratio range at test condition B (fig. 9(c)). When a larger fixed-area nozzle (model 42) was used, the operating range was limited to high fuel-air ratios only, and combustion was very rough. The performance of combustor model 41 with the wide-range pintle nozzle (fig. 6) installed was about the same as that with air atomization, except at high fuel-air ratios at test condition E (fig. 9(a)) where air atomization produced considerably higher efficiency.

## Effect of Primary-Air Baffles

In attempts to raise the combustion efficiency level of the variable-area combustor, baffles (fig. 5(c)) were attached to the fuel disk to cause major changes in the air-flow patterns in the primary zone. The slotted disk and V-gutter baffles (models 20 and 21) were designed to increase turbulence in the primary zone, and a plain cone-shaped disk (model 25) was designed to increase reverse flow in the center of the combustor. The fuel was atomized by air in these three models. Typical results obtained are presented in figure 10.

At test condition A (fig. 10(a)), models 20 and 21 burned with approximately the same efficiency as the basic combustor model 10. At test condition B (fig. 10(b)), model 20 burned with slightly higher efficiency than model 10, whereas model 21 burned with lower efficiencies. The plain disk baffle (model 25) performed with low efficiency at both test conditions.

## Performance Characteristics of Best Models

Variable-area combustor models having improved performance characteristics were developed by adding new features to some of the models previously discussed. The combustion efficiencies of these models are presented in figure 11.

High-efficiency model. - A small pilot fuel spray was added inside the plain disk baffle of model 25 to provide additional fuel in this region. A row of 0.375-inch holes was added in the liner 6 inches

downstream of the fuel disk to increase the reverse flow of air in the primary zone. Finally, another row of 0.25-inch holes with fuel dams were added in the liner 3 inches downstream from the fuel disk to recirculate the fuel which had impinged on the liner walls. The combination of all these changes resulted in a combustor (model 29) having higher combustion-efficiency performance than any other model investigated over most of the range. For both air flows at a combustor-inlet pressure of 15 inches of mercury absolute (conditions E and A, figs. 11(a) and (b)) the combustion efficiency varied from 90 percent at a fuel-air ratio of 0.008 to 85 percent at a fuel-air ratio of 0.026. At condition 3553
B, 8 inches of mercury absolute (fig. 11(c)), the efficiency varied from 81 percent at a fuel-air ratio of 0.013 to 69 percent at a fuel-air ratio of 0.026. Although the highest efficiency was obtained with model 29 the combustion was characterized by rough burning.

Wide-range model. - Several changes were made in combustor model 29 in an attempt to increase the operable range at high fuel-air ratios and to increase the combustion efficiency. The combustor having the widest operating range (model 46) was similar to model 29 except that the small fixed-area pilot nozzle was replaced by the wide-range pintle nozzle and four smaller fuel holes were used for air atomization (fig. 5(d)). These changes allowed a large percentage of the fuel to penetrate further downstream in the combustor.

At high fuel-air ratios at test condition B, the performance of model 46 was better than all other models in both range and efficiency (fig. 11(c)). Blow-out occurred at a fuel-air ratio of 0.041, where the efficiency was approximately 60 percent. The range at the other conditions A and E was about the same as that of model 29; however, the efficiency level was somewhat lower. Model 46 was also characterized by rough burning.

Combustor total-pressure loss. - Typical total-pressure-loss data, obtained with several variable-area combustors with plain disk baffles are presented in figure 12. The pressure-loss data are plotted as a function of combustor-inlet to -outlet density ratio. At a constant primary-air setting, pressure drop increased linearly with density ratio. When the primary-air flow was increased by increasing the area of the air openings, the pressure drop was reduced.

A curve representing the pressure loss of model 29 at test condition E and at the primary-air settings required for maximum combustion efficiency is shown in figure 12(a). If a constant area setting of 11 percent primary air were used (equivalent to a fixed-geometry combustor), the total-pressure loss would increase from approximately 20 to 25 times the reference velocity pressure for an increase in density ratio across the combustor from 1.0 to 3.2. With variable-air admission (model 29), the pressure loss was only 21 times the reference velocity pressure at the density ratio of 3.2 (equivalent to a combustor temperature rise of 1400° F), a decrease of 16 percent from the fixed-area-setting curve.

Temperature profile. - A typical combustor-outlet temperature profile for the high-efficiency model 29 is presented in figure 13. In general, the temperatures were uniform within ±200° F, although occasionally an eccentric profile was recorded. The eccentricity was usually caused by misalinement of parts in the primary-air passages, or eccentricity of the liner at the combustor outlet.



## DISCUSSION

### Combustor Design Variables

The results of this investigation showed that, by continuously varying the primary-air flow, it was possible to achieve nearly constant combustion efficiency over wide ranges of fuel-air ratio. The design features incorporated into the combustor permitted the primary-zone fuel-air ratio to be maintained at a near-optimum value at all operating conditions.



From a consideration of the design of the variable-area combustor and the results obtained with the various experimental models investigated, several trends are indicated that may be useful in the design of turbojet combustors.

Fuel introduction. - When air atomization alone was employed, fewer holes in the fuel disk improved performance. This result tends to substantiate the theory that alternate air-rich and fuel-rich regions in a combustor primary zone aids combustor performance (ref. 7). Although no marked effect of hole size on performance was noted, there are limits on the size that can be used. If small holes are used, fuel cannot be supplied over the complete range of operation of an engine without excessive fuel system pressures, or if the holes are very large, performance will probably decrease and vapor-lock problems will increase. Similarly, there are size limits for the fixed-area spray nozzles used in some configurations. For example, the fixed-area nozzle of combustor model 34 was too small to permit operation over the complete range of engine conditions, whereas the large nozzle in combustor model 42 allowed combustor operation at high fuel-air ratios (fig. 9) but provided insufficient atomization at low fuel flows.

It was found that for the experimental combustor configurations investigated, air and mechanical atomization of the fuel gave approximately equal performance; the best performing models (29 and 46) used a combination of the two. These results suggest the use of primary air to aid atomization of poorly developed sprays now obtained with conventional fixed-area spray nozzles at low fuel flows. Photographs of liquid sprays obtained in a tubular turbojet combustor (ref. 8) are further evidence of the extent to which air flows may aid atomization.

Rough burning in the variable-area combustor (table II) usually occurred at lean primary fuel-air ratios although occasionally it would occur at the rich end. In model 42, with the large fixed-area nozzle, the burning was very rough probably because of the poor atomization. The rough burning encountered in the best models (29 and 46) appeared 3553
to be associated with the use of fuel dams, which may have influenced the fuel preparation or the air-flow patterns in the primary zone.

Air-flow patterns. - The use of baffles in the primary zone markedly affected combustion efficiency (fig. 10). The slotted-disk baffle (model 20) and the V-gutter baffle (model 21) were designed to increase turbulence in the primary zone. The difference in performance may be accounted for by the different degrees of turbulence created by the two baffles. The plain-disk baffle (model 25) was designed to promote reverse flow in the center of the combustor primary zone. A small fuel spray was required inside the baffle to provide a hot piloting region. Additional liner holes and fuel dams were required to further promote reverse flow and mixing of the fuel and air in the primary zone to achieve the high combustion efficiency of model 29.

The results obtained with the variable-area combustor models investigated indicate that both air-flow patterns and fuel introduction affect the results obtained and that both must be varied to achieve the optimum configuration. The best models (29 and 46) were developed by this technique.

Control system. - The over-all fuel-air ratios (100-percent combustion efficiency assumed) required for operation of one current turbojet engine at a flight Mach number of 0.6 are presented in figure 14. Higher fuel-air ratios are required at high engine speeds but they occur at lower fuel-flow rates as altitude is increased. The shape of the curves also changes with flight speed. The design principle of the variable-area combustor is to increase primary-air flow with increase in these over-all fuel-air ratios to maintain primary-fuel-air ratio near optimum values.

No single engine variable shown in figure 14 (fuel flow, engine speed, altitude, or flight speed) can theoretically be used as a precise signal source to actuate the primary-air-flow control mechanism if the variable-area design principle is to be used in an engine. Such a precise control signal would have to be obtained from a combination of engine variables; such as fuel flow and combustor inlet-air density, or engine speed, altitude, and flight speed.

The data presented for several models of the experimental variable-area combustor show that maximum combustion efficiency is obtained only when the proper amount of primary air is provided; however, in some models maximum efficiency is obtained over a considerable portion of the fuel-air-ratio range at one primary-air-flow setting. This suggests the possibility of a two- or three-position control for primary-air setting instead of continuous control or use of a single variable such as engine speed to provide a signal source. The off-design performance may not be seriously lowered by this method. Figure 15 illustrates one possible method for utilizing a control signal to vary the primary-air openings in the combustor. The bellows assembly is linked to the throat section by the movable sleeve. The control pressure signal acts on the bellows area to adjust the throat section and maintain the optimum quantity of primary-air flow.

## Performance of Best Variable-Area Combustor

The combustion-efficiency performance of model 29 variable-area combustor is compared with that of several other experimental combustors (refs. 5, 9, and 10) and with a reference production combustor, all of approximately the same nominal size, in figure 16. Two lines of constant combustor temperature rise are also shown in figure 16 to represent engine cruise operation (680° F) and maximum engine speed (1180° F) conditions. These lines show the increase in fuel-air ratio that is required when loss of combustion efficiency occurs. The data indicate, in general, that all the experimental combustors represented have efficiency levels near 90 percent at test conditions A and E (pressure, 15 in. Hg abs). Greater differences in performance are exhibited at the more severe test condition B (pressure, 8 in. Hg abs); the efficiency of the prevaporizing combustor (ref. 9) was from 3 to 11 percentage points higher than that of the variable-area combustor. It is also noted in figure 16 that all the experimental combustors operated with efficiencies higher than that of the reference production combustor, particularly at lean fuel-air ratios and at low pressures. The efficiency of model 29 was as much as 25 percent higher than that of the reference production combustor at the engine cruise conditions. At maximum engine speed conditions, however, the efficiency of model 29 was about 3 percent lower. All the experimental combustors were, however, designed without regard for other combustion-chamber problems such as durability, carbon deposition tendencies, and ease of manufacture.

The range of fuel-air ratios over which model 29 would operate was only slightly greater than that of the reference combustor (fig. 16). Modification of the fuel-introduction system of model 29, however, resulted in a configuration (model 46) that operated at fuel-air ratios from 0.007 to 0.041 at test condition B (fig. 11(c)). This operating range is about three times that of the reference combustor (0.014 to 0.027) at the same test condition. The combustion efficiency of model 46 was about 3 to 5 percent lower than that of model 29 over much of the operating range.

The fact that all the experimental combustors represented in figure 16 have approximately the same performance indicates that combustor performance may be limited by the size of the combustor. Data obtained with combustors of different size substantiate this possibility. A relation between combustion efficiency and combustor size, as expressed by the hydraulic radius of the combustor liner at the point where the undisturbed fuel spray strikes the liner walls, is presented in reference 11. The comparison of different combustors was made at operation conditions of equal severity as expressed by the parameter $V_r/P_iT_i$ (where 3553 $V_r$ is the combustor reference velocity, calculated from inlet density, mass-flow rate, and maximum combustor cross-sectional area, ft/sec; $P_i$ is the combustor-inlet static pressure, lb/sq ft abs; and $T_i$ is the combustor-inlet temperature, °R).

Values of combustion efficiency and hydraulic radius for several experimental and production combustors, including those of reference 11, are presented in table III for two values of the severity factor ($V_r/P_iT_i$ equal to 100 and $248\times10^{-6}$). The combustion-efficiency data shown in table III were obtained from the faired curves of reference 12 (based on the reciprocal of $V_r/P_iT_i$) and from the other reference sources at a combustor temperature rise of 680° F, which is representative of the current requirement for engine cruise operation. At the high value of $V_r/P_iT_i$, the performance is also shown for a temperature rise of 1180° F, which represents the requirements for maximum engine speed. These data are plotted in figure 17. The major objective of the experimental combustors was high combustion efficiency at low pressures and the results (fig. 17) show that most of these combustors have efficiencies well above the production combustors at both values of $V_r/P_iT_i$. The curve faired through the experimental data for combustors having the highest efficiencies suggest that the maximum performance attainable is limited by the size of the combustor. The variable-area combustor data point is near the upper curve at both severity factors; thus its performance may also be limited by its size. The lower production combustor curve in figure 17(a) was obtained from reference 11. In general, for both production and experimental combustors, efficiency increases with increase in hydraulic radius. The curves indicate that a hydraulic radius of 2.0 inches or greater is required to achieve 100-percent efficiency at the lower severity factor with the fuels and equipment now being used.

In figure 17, the scatter of the data is greater at the more severe condition, which indicates the difficulty of achieving high efficiency at high values of $V_r/P_iT_i$. The effect of combustor length is not considered here and may account for some of the spread of the data.

The effect of combustor temperature rise on combustion efficiency is illustrated in figure 17(b) by the tailed symbols. In general, the efficiency decreased from 8 to 14 percentage points as the temperature rise increased from 680° F (upper faired curve) to 1180° F. Data for a similar increase in temperature rise was available for only one production combustor (table III). This combustor showed an increase in efficiency from 57 to 71 percent for the increase in temperature rise. Its performance was thus close to the best of the experimental combustors of the same nominal size at the higher value of temperature rise. The
3553 decrease in efficiency with the decrease in combustor size is not yet well understood. Some possible factors are wall quenching effects, fuel impingement on the walls, or fuel and air mixing limitations due to combustor size.

Pressure loss. - It is shown (fig. 12) that the pressure drop could be decreased with increased density ratio (or temperature rise) when the primary-air openings were varied for maximum combustion efficiency. If continuous control of the primary-air areas were used instead of stepwise changes, it appears possible that the combustor pressure loss could be maintained at a nearly constant value over the complete range of fuel-air ratios.

The pressure losses of the variable-area combustor investigated were higher than current practice (isothermal pressure drop of a representative production combustion is 12.0). Nevertheless, it is believed that proper redesign of the front end of the combustor would result in marked reductions in pressure loss.

Temperature profile. - The data presented indicate that it is possible to obtain a flat temperature profile even though all the secondary air enters in only the last 5 inches of the liner. Since all the fuel and primary air enters at the upstream end of the combustor liner, a relatively uniform temperature profile is probably achieved by the time the hot gases reach the secondary-air slots. It is believed that control of combustor-outlet temperature profile could be attained by simple changes in the secondary-air openings.

## CONCLUDING REMARKS

Variable primary-air flow has been shown to be another method of extending the rich limit of combustion in addition to fuel staging; however, either method involves a more complex combustor design and a more complex control system to regulate the new variable. This complexity must be weighed against possible gains that the data indicate.

The major advantage of the variable-area combustor was the extension of high efficiency over greater fuel-air-ratio ranges. The combustor failed, however, to perform with efficiencies much higher than 90 percent, which was attributed to the small size of the combustor.

## SUMMARY OF RESULTS

An investigation was conducted with experimental combustor designs incorporating a means of varying the primary-air flow. The performance of the best configurations at high-altitude operating conditions are summarized in the following paragraphs. The values quoted for simulated flight performance refer to combustor operating conditions in a typical 5.2-pressure-ratio turbojet engine at a flight Mach number of 0.6. 3553

1. The primary-air flow markedly affected combustion efficiency. Maximum efficiency was obtained with increased primary-air flow as over-all fuel-air ratio was increased.

2. Combustion efficiencies obtained were as high as 89 percent at cruise speed at 56,000 feet and as high as 82 percent at 70,000 feet. At the cruise condition, the efficiencies of the best experimental model were as much as 25 percent higher than those of a reference production combustor of equal size. At full-rated engine speed, however, the efficiencies of the experimental model were 3 percent lower.

3. The range of fuel-air ratios over which the combustor would operate without blow-out was increased with use of variable air admission. At the 70,000-foot condition, the fuel-air-ratio range of one combustor model (model 46) was three times the range of a reference production combustor.

4. The increase in combustor pressure loss with increase in combustor temperature rise was reduced when variable primary-air admission was used. The pressure-loss level, however, was higher for the models investigated than for current production combustors.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, February 14, 1955

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TABLE I. - FUEL ANALYSIS

| Fuel Properties | MIL-F-5624B (JP-4) (NACA fuel 52-53) |
|---|---|
| A.S.T.M. distillation D86-46, $^{\circ}$F | |
| Initial boiling point | 136 |
| Percent evaporated | |
| 5 | 183 |
| 10 | 200 |
| 20 | 225 |
| 30 | 244 |
| 40 | 263 |
| 50 | 278 |
| 60 | 301 |
| 70 | 321 |
| 80 | 347 |
| 90 | 400 |
| Final boiling point | 498 |
| Residue, percent | 1.2 |
| Loss, percent | 0.7 |
| Aromatics, percent by volume | |
| A.S.T.M. D875-46T | 8.5 |
| Silica gel | 10.7 |
| Specific gravity | 0.757 |
| Viscosity, centistokes at 100$^{\circ}$ F | 0.762 |
| Reid vapor pressure, lb/sq in. | 2.9 |
| Hydrogen-carbon ratio | 0.170 |
| Net heat of combustion, Btu/lb | 18,700 |

3553

3553

CD-3

TABLE II. - EXPERIMENTAL DATA

| Run | Combustor crank setting | Combustor-inlet total pressure, $P_i$, in. Hg abs | Combustor-inlet total temperature, $T_i$, $^{\circ}F$ | Air-flow rate, lb/sec | Air-flow rate per unit area, lb/(sec)(sq ft) | Combustor reference velocity, $V_r$, ft/sec | Fuel-flow rate, lb/hr | Fuel-air ratio | Mean combustor-outlet total temperature, $^{\circ}F$ | Mean combustor temperature rise, $^{\circ}F$ | Combustion efficiency, percent | Total pressure-loss through combustor, in. water | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model 10 | | | | | | | | | | | | | |
| 710 | 0 | 7.9 | 268 | 0.397 | 1.487 | 103.4 | 28.7 | 0.0201 | 1185 | 917 | 65.7 | ---- | |
| 711 | ↓ | 7.9 | 265 | .395 | 1.480 | 102.6 | 26.0 | .0183 | 1150 | 885 | 69.2 | ---- | |
| 712 | ↓ | 8.0 | 272 | .396 | 1.484 | 102.5 | 22.5 | .0158 | 1075 | 803 | 72.0 | ---- | |
| 713 | ↓ | ↓ | 266 | .397 | 1.487 | 101.9 | 29.6 | .0207 | 1200 | 934 | 65.1 | ---- | |
| 714 | ↓ | ↓ | 271 | .394 | 1.476 | 101.9 | 28.7 | .0202 | 1225 | 954 | 68.1 | ---- | |
| 715 | ↓ | ↓ | 271 | .398 | 1.490 | 102.8 | 31.5 | .0220 | 1255 | 984 | 65.1 | ---- | |
| 716 | ↓ | ↓ | 270 | .403 | 1.509 | 103.9 | 35.0 | .0241 | 1240 | 970 | 58.7 | ---- | |
| 717 | ↓ | ↓ | 272 | .404 | 1.514 | 104.6 | 37.0 | .0255 | 1220 | 948 | 54.4 | ---- | (a) |
| 718 | 5 | 8.0 | 268 | .405 | 1.517 | 103.9 | 51.5 | .0353 | 1210 | 944 | 40.1 | ---- | |
| 719 | ↓ | 8.0 | 270 | .397 | 1.487 | 102.4 | 49.0 | .0344 | 1240 | 970 | 42.3 | ---- | |
| 720 | ↓ | 8.1 | 268 | .402 | 1.505 | 102.1 | 46.5 | .0321 | 1330 | 1062 | 49.5 | ---- | |
| 721 | ↓ | 8.0 | 268 | .399 | 1.495 | 102.4 | 43.5 | .0303 | 1325 | 1059 | 52.1 | ---- | |
| 722 | ↓ | 7.9 | 266 | .400 | 1.499 | 104.0 | 40.5 | .0281 | 1280 | 1014 | 53.4 | ---- | |
| 723 | 5 | 8.0 | 265 | .398 | 1.490 | 101.9 | 39.0 | .0272 | 1320 | 1055 | 57.2 | ---- | (b) |
| 725 | 0 | 8.1 | 276 | .398 | 1.490 | 102.2 | 34.7 | .0242 | 1270 | 994 | 60.0 | 13.0 | |
| 726 | ↓ | 8.0 | 266 | ↓ | ↓ | 102.1 | 31.7 | .0221 | 1240 | 974 | 63.9 | 13.1 | |
| 727 | ↓ | 7.9 | 270 | ↓ | ↓ | 103.9 | 28.4 | .0198 | 1205 | 935 | 68.0 | 13.1 | |
| 728 | ↓ | 8.0 | 274 | ↓ | ↓ | 103.2 | 26.8 | .0187 | 1170 | 896 | 68.8 | 12.8 | |
| 729 | ↓ | 8.0 | 264 | ↓ | ↓ | 101.8 | 25.0 | .0161 | 1090 | 826 | 72.8 | 12.6 | |
| 730 | ↓ | 8.0 | 262 | ↓ | ↓ | 101.5 | 20.0 | .0139 | 1005 | 743 | 74.5 | 12.5 | |
| 731 | ↓ | 8.0 | 269 | ↓ | ↓ | 102.5 | 35.2 | .0246 | 1280 | 1011 | 60.4 | 12.8 | |
| 732 | ↓ | ---- | ---- | ↓ | ↓ | ----- | 37.7 | .0263 | ---- | ---- | ---- | ---- | (a) |
| 733 | 5 | 8.0 | 266 | .398 | 1.490 | 102.1 | 43.6 | .0304 | 1340 | 1074 | 52.7 | 11.5 | |
| 734 | ↓ | 8.0 | 269 | ↓ | ↓ | 102.5 | 40.0 | .0279 | 1325 | 1056 | 56.0 | 11.5 | |
| 735 | ↓ | 8.1 | 265 | ↓ | ↓ | 100.7 | 46.5 | .0324 | 1330 | 1065 | 49.2 | 11.4 | |
| 736 | ↓ | 8.0 | 264 | ↓ | 1.491 | 101.8 | 49.1 | .0342 | 1250 | 986 | 43.1 | 11.5 | |
| 737 | ↓ | ↓ | 266 | ↓ | ↓ | 102.1 | 47.6 | .0332 | 1270 | 1004 | 45.2 | 11.6 | |
| 738 | ↓ | ↓ | 268 | ↓ | ↓ | 102.4 | 52.0 | .0362 | 1210 | 942 | 39.1 | 11.6 | |
| 739 | 6 | 8.0 | 264 | .397 | 1.487 | 101.6 | 52.0 | .0364 | 1325 | 1061 | 44.0 | 11.2 | |
| 740 | ↓ | 8.0 | 272 | .395 | 1.479 | 102.1 | 39.5 | .0278 | 1400 | 1128 | 60.4 | 11.0 | (b) |
| 741 | ↓ | 8.1 | 270 | .397 | 1.487 | 101.1 | 45.2 | .0316 | 1470 | 1200 | 57.2 | 11.1 | (b) |
| 742 | ↓ | 8.0 | 268 | .397 | 1.487 | 102.1 | 48.4 | .0338 | 1360 | 1092 | 48.6 | 11.2 | |
| 743 | ↓ | 8.0 | 266 | .396 | 1.483 | 101.6 | 53.9 | .0378 | 1320 | 1054 | 42.4 | 11.2 | |
| 744 | 2.5 | 8.0 | 272 | .398 | 1.491 | 103.0 | 34.9 | .0244 | 1260 | 988 | 59.4 | 12.0 | |
| 745 | ↓ | 7.9 | 270 | .395 | 1.479 | 103.1 | 38.7 | .0272 | 1160 | 890 | 48.0 | 11.8 | |
| 746 | ↓ | 8.0 | 270 | ↓ | ↓ | 101.9 | 47.0 | .0331 | 1070 | 800 | 35.9 | 11.8 | |
| 747 | ↓ | ↓ | 264 | ↓ | ↓ | 101.0 | 33.0 | .0232 | 1280 | 1016 | 63.9 | 11.6 | |
| 748 | ↓ | ↓ | 268 | ↓ | ↓ | 101.6 | 29.8 | .0210 | 1250 | 982 | 68.0 | 11.7 | |
| 749 | ↓ | 7.9 | 272 | ↓ | ↓ | 103.4 | 25.4 | .0178 | 1165 | 913 | 73.3 | 11.6 | |
| 750 | 0 | 15.0 | 271 | .573 | 2.146 | 78.93 | 51.2 | .0248 | 1595 | 1324 | 79.5 | 13.8 | |
| 751 | ↓ | ↓ | 270 | ↓ | ↓ | 78.82 | 47.3 | .0230 | 1625 | 1255 | 81.0 | 13.6 | |
| 752 | ↓ | ↓ | 272 | ↓ | ↓ | 79.04 | 43.4 | .0211 | 1450 | 1178 | 82.2 | 13.4 | |
| 753 | ↓ | 15.1 | 271 | .570 | 2.135 | 78.00 | 46.0 | .0224 | 1500 | 1229 | 80.7 | 13.2 | |
| 754 | ↓ | 15.1 | 270 | ↓ | ↓ | 77.89 | 55.7 | .0272 | 1690 | 1420 | 78.9 | 13.4 | |
| 755 | ↓ | 15.0 | 268 | ↓ | ↓ | 78.20 | 38.5 | .0192 | 1390 | 1122 | 84.8 | 12.6 | |
| 756 | ↓ | ↓ | 265 | ↓ | ↓ | 77.87 | 35.7 | .0174 | 1295 | 1030 | 85.2 | 12.4 | (b) |
| 757 | ↓ | ↓ | 270 | ↓ | ↓ | 78.41 | 33.0 | .0161 | 1250 | 960 | 85.4 | 12.4 | (b) |
| 758 | ↓ | ↓ | 272 | ↓ | ↓ | 78.63 | 29.0 | .0141 | 1140 | 868 | 87.0 | 12.2 | (b) |
| 759 | 5 | 15.0 | 271 | .570 | 2.135 | 78.52 | 43.1 | .0210 | 1460 | 1169 | 83.1 | 11.0 | (b) |
| 760 | ↓ | 15.0 | 272 | ↓ | ↓ | 78.63 | 46.2 | .0225 | 1540 | 1268 | 83.2 | 11.2 | |
| 761 | ↓ | 15.1 | 267 | ↓ | ↓ | 77.58 | 51.0 | .0249 | 1640 | 1373 | 82.6 | 11.5 | |
| 762 | ↓ | 15.0 | 272 | .565 | 2.116 | 77.93 | 57.3 | .0281 | 1740 | 1468 | 79.0 | 12.2 | |
| 763 | ↓ | 14.9 | 264 | .570 | 2.135 | 78.29 | 40.0 | .0195 | 1410 | 1146 | 85.6 | 10.8 | |
| 764 | ↓ | 15.0 | 264 | ↓ | ↓ | 77.77 | 39.5 | .0192 | 1395 | 1131 | 85.5 | 10.8 | |
| 765 | ↓ | ↓ | 270 | ↓ | ↓ | 78.41 | 35.5 | .0173 | 1290 | 1020 | 84.8 | 10.5 | |
| 766 | ↓ | ↓ | 267 | ↓ | ↓ | 78.09 | 32.5 | .0158 | 1205 | 938 | 84.5 | 10.2 | (b) |
| 767 | 10 | 15.0 | 266 | .570 | 2.135 | 77.58 | 40.7 | .0199 | 1415 | 1149 | 84.5 | 10.8 | (b) |
| 768 | ↓ | ↓ | 271 | ↓ | ↓ | 78.52 | 35.5 | .0173 | 1300 | 1029 | 85.6 | 10.7 | (b) |
| 769 | ↓ | ↓ | 272 | ↓ | ↓ | 78.63 | 44.9 | .0219 | 1510 | 1258 | 83.5 | 10.9 | (b) |
| 770 | ↓ | ↓ | 269 | ↓ | ↓ | 78.30 | 49.7 | .0242 | 1620 | 1351 | 83.1 | 11.0 | (b) |
| 771 | ↓ | ↓ | 265 | .565 | 2.116 | 77.19 | 54.9 | .0270 | 1730 | 1465 | 82.0 | 11.2 | (b) |
| 772 | 0 | 15.1 | 271 | .735 | 2.753 | 100.6 | 50.1 | .0190 | 1375 | 1104 | 84.7 | 21.2 | |
| 773 | ↓ | 15.0 | 268 | ↓ | ↓ | 100.8 | 48.3 | .0175 | 1310 | 1042 | 85.8 | 21.4 | |
| 774 | ↓ | ↓ | 267 | ↓ | ↓ | 100.7 | 43.8 | .0166 | 1245 | 978 | 84.5 | 21.2 | |
| 775 | ↓ | ↓ | 271 | ↓ | ↓ | 101.2 | 39.2 | .0148 | 1185 | 914 | 87.5 | 20.9 | |
| 776 | ↓ | ↓ | 266 | ↓ | ↓ | 100.6 | 34.4 | .0130 | 1075 | 809 | 87.3 | 20.5 | |
| 777 | ↓ | ↓ | 264 | .730 | 2.734 | 99.59 | 31.7 | .0121 | 1025 | 761 | 88.0 | 20.0 | |
| 778 | ↓ | ↓ | 270 | .735 | 2.753 | 101.1 | 55.2 | .0208 | 1455 | 1185 | 83.2 | 21.7 | |
| 779 | ↓ | ↓ | 271 | .730 | 2.734 | 100.8 | 61.6 | .0235 | 1525 | 1254 | 79.2 | 22.1 | |
| 780 | ↓ | ↓ | 268 | .735 | 2.753 | 100.9 | 65.5 | .0248 | 1550 | 1282 | 77.0 | 22.3 | |
| 781 | 5 | 15.0 | 268 | .730 | 2.734 | 100.1 | 65.2 | .0248 | 1625 | 1357 | 81.8 | 19.1 | |
| 782 | ↓ | ↓ | 264 | .735 | 2.753 | 100.3 | 59.1 | .0223 | 1550 | 1286 | 85.0 | 18.7 | |
| 783 | ↓ | ↓ | 269 | .730 | 2.734 | 100.3 | 52.8 | .0200 | 1455 | 1186 | 86.3 | 18.0 | |
| 784 | ↓ | ↓ | 265 | .735 | 2.753 | 100.4 | 48.1 | .0182 | 1360 | 1095 | 87.0 | 18.1 | |
| 785 | ↓ | ↓ | 272 | ↓ | ↓ | 101.4 | 44.9 | .0170 | 1290 | 1018 | 86.1 | 18.1 | |
| 786 | ↓ | ↓ | 267 | ↓ | ↓ | 100.7 | 37.9 | .0143 | 1135 | 868 | 85.5 | 17.3 | (b) |
| 787 | ↓ | ↓ | 266 | .725 | 2.715 | 99.17 | 40.7 | .0156 | 1200 | 934 | 85.2 | 17.3 | |
| 788 | 10 | 15.0 | 272 | .725 | 2.715 | 99.99 | 56.5 | .0213 | 1470 | 1198 | 82.6 | 17.8 | |
| 789 | ↓ | ↓ | 270 | .730 | 2.734 | 100.4 | 61.3 | .0233 | 1580 | 1310 | 83.5 | 18.4 | (c) |
| 790 | ↓ | ↓ | 268 | .735 | 2.753 | 100.8 | 47.1 | .0178 | 1225 | 957 | 77.1 | ---- | (c) |
| 791 | 0 | 15.1 | 271 | .980 | 3.670 | 134.1 | 51.3 | .0149 | 1160 | 889 | 84.6 | 37.2 | |
| 792 | ↓ | 15.1 | 266 | .965 | 3.614 | 131.1 | 58.8 | .0163 | 1210 | 944 | 82.5 | 37.8 | |
| 793 | ↓ | 14.9 | 269 | .965 | 3.614 | 133.4 | 62.3 | .0179 | 1260 | 991 | 79.5 | ---- | |
| 794 | ↓ | 14.9 | 270 | .950 | 3.558 | 131.6 | 43.9 | .0128 | 1060 | 790 | 86.4 | ---- | |
| 795 | ↓ | 15.0 | 266 | .955 | 3.577 | 130.7 | 40.4 | .0117 | 995 | 729 | 66.7 | ---- | |

[a] Blow-out.

[b] Rough burning.

[c] Very rough burning.

[redacted]

TABLE II. - Continued. EXPERIMENTAL DATA

| Run | Combustor crank setting | Combustor-inlet total pressure, $P_i$, in. Hg abs | Combustor-inlet total temperature, $T_i$, °F | Air-flow rate, lb/sec | Air-flow rate per unit area, lb/(sec)(sq ft) | Combustor reference velocity, $V_r$, ft/sec | Fuel-flow rate, lb/hr | Fuel-air ratio | Mean combustor-outlet total temperature, °F | Mean combustor temperature rise, °F | Combustion efficiency, percent | Total pressure-loss through combustor, in. water | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Model 20 | | | | | | | |
| 796 | 0 | 8.0 | 268 | 0.401 | 1.502 | 103.2 | 29.0 | 0.0201 | 1265 | 997 | 71.8 | ---- | |
| 797 | | | 266 | | | 102.9 | 26.0 | .0180 | 1235 | 969 | 77.3 | ---- | |
| 798 | | | 270 | | | 103.4 | 22.2 | .0153 | 1100 | 830 | 76.8 | ---- | (a,b) |
| 799 | | | 267 | | | 103.0 | 25.7 | .0178 | 1190 | 923 | 74.3 | 12.8 | |
| 800 | | 8.1 | 270 | | | 102.2 | 28.7 | .0199 | 1235 | 965 | 70.1 | 12.7 | |
| 801 | | 8.1 | 266 | | | 101.6 | 32.2 | .0223 | 1285 | 1019 | 66.5 | 12.9 | |
| 807 | 10 | 8.1 | 270 | .401 | 1.502 | 102.2 | 31.7 | .0220 | 1290 | 1020 | 67.6 | 9.6 | (b) |
| 808 | | | 273 | | | 102.6 | 35.5 | .0246 | 1400 | 1127 | 67.8 | 9.8 | |
| 809 | | | 272 | | | 102.4 | 38.4 | .0266 | 1445 | 1173 | 65.6 | 10.0 | |
| 810 | | 8.0 | 273 | | | 103.9 | 41.2 | .0286 | 1490 | 1217 | 63.9 | 10.4 | |
| 811 | | 7.8 | 272 | .402 | 1.506 | 106.7 | 31.7 | .0219 | 1280 | 1008 | 67.0 | ---- | |
| 822 | 0 | 14.9 | 271 | .741 | 2.775 | 102.7 | 24.6 | .0092 | 870 | 599 | 89.3 | 20.4 | |
| 823 | | 15.0 | 268 | .741 | 2.775 | 101.6 | 21.4 | .0080 | 790 | 522 | 88.9 | 19.8 | |
| 830 | 5 | 15.0 | 270 | .740 | 2.772 | 101.8 | 60.5 | .0227 | 1540 | 1270 | 82.6 | 18.7 | |
| 833 | | | 270 | .739 | 2.768 | 101.7 | 53.3 | .0200 | 1440 | 1170 | 85.4 | 18.0 | |
| 834 | | | 268 | .739 | 2.768 | 101.4 | 47.8 | .0180 | 1345 | 1077 | 86.4 | ---- | |
| 835 | | | 263 | .740 | 2.772 | 100.8 | 42.6 | .0160 | 1235 | 972 | 86.8 | ---- | |
| 836 | | | 269 | | | 101.7 | 37.9 | .0143 | 1160 | 891 | 88.2 | 16.9 | |
| 837 | | | 268 | | | 101.5 | 33.0 | .0124 | 1060 | 792 | 89.4 | ---- | |
| 838 | | | 270 | .739 | 2.768 | 101.7 | 25.7 | .0097 | 900 | 630 | 89.5 | ---- | |
| 844 | 10 | 15.0 | 262 | .742 | 2.779 | 101.0 | 64.2 | .0240 | 1595 | 1333 | 82.5 | 17.4 | |
| 845 | | | 269 | | | 101.9 | 71.0 | .0266 | 1710 | 1441 | 81.7 | ---- | |
| 846 | | | 265 | | | 101.4 | 75.2 | .0282 | 1780[c] | 1515 | 81.7 | ---- | (d) |
| | | | | | | Model 21 | | | | | | | |
| 867 | 0 | 8.0 | 273 | 0.396 | 1.483 | 102.6 | 23.0 | 0.0161 | 1030 | 757 | 66.4 | 13.0 | |
| 868 | | 8.0 | 266 | | | 101.6 | 20.0 | .0140 | 985 | 719 | 71.8 | 12.8 | |
| 869 | | 8.1 | 265 | | | 100.2 | 25.5 | .0179 | 1110 | 845 | 67.3 | ---- | |
| 870 | | 8.0 | 266 | | | 101.6 | 28.4 | .0199 | 1160 | 894 | 64.5 | ---- | |
| 871 | | 8.0 | 276 | .397 | 1.487 | 103.2 | 30.9 | .0216 | 1195 | 919 | 61.5 | 13.2 | |
| 872 | | 8.0 | 266 | .397 | 1.487 | 101.8 | 34.1 | .0238 | 1175 | 909 | 55.4 | ---- | (b) |
| 877 | | 15.0 | 270 | .742 | 2.779 | 102.1 | 37.8 | .0142 | 1120 | 850 | 84.6 | ---- | (b) |
| 878 | | | 272 | .741 | 2.775 | 102.2 | 33.9 | .0127 | 1050 | 778 | 85.8 | ---- | (b) |
| 879 | | | 272 | .740 | 2.772 | 102.1 | 30.5 | .0115 | 995 | 723 | 87.5 | 21.1 | |
| 880 | | 14.9 | 264 | .739 | 2.768 | 101.5 | 29.0 | .0109 | 960 | 696 | 88.5 | 21.0 | |
| 881 | 5 | 15.2 | 269 | .740 | 2.772 | 100.3 | 43.4 | .0163 | 1235 | 966 | 84.7 | 17.2 | |
| 882 | | 15.0 | 271 | .741 | 2.776 | 102.1 | 46.8 | .0176 | 1290 | 1019 | 83.5 | ---- | |
| 883 | | | 272 | .740 | 2.772 | 102.1 | 49.9 | .0187 | 1335 | 1063 | 83.7 | ---- | |
| 884 | | | 272 | .741 | 2.776 | 102.2 | 53.6 | .0201 | 1410 | 1138 | 82.7 | ---- | |
| 885 | | | 264 | .741 | 2.775 | 101.1 | 56.6 | .0212 | 1460 | 1196 | 82.4 | 18.6 | |
| 886 | | | 270 | .740 | 2.772 | 101.8 | 61.6 | .0232 | 1540 | 1270 | 81.4 | ---- | |
| | | | | | | Model 24 | | | | | | | |
| 937 | 0 | 15.1 | 266 | 0.742 | 2.779 | 100.8 | 46.5 | 0.0174 | 1310 | 1044 | 86.5 | 19.2 | |
| 938 | | 15.0 | 267 | | | 101.7 | 42.0 | .0157 | 1240 | 973 | 88.2 | ---- | |
| 939 | | 15.1 | 270 | | | 101.4 | 40.0 | .0150 | 1200 | 930 | 88.4 | ---- | |
| 940 | | 15.1 | 269 | .740 | 2.772 | 101.0 | 36.5 | .0137 | 1130 | 861 | 88.6 | 18.6 | (b) |
| 941 | | 15.0 | 267 | .740 | 2.772 | 101.4 | 49.7 | .0187 | 1390 | 1123 | 87.1 | ---- | |
| 942 | | 15.1 | 269 | .750 | 2.809 | 102.3 | 55.2 | .0205 | 1460 | 1191 | 85.2 | ---- | |
| 943 | | 15.0 | 268 | .747 | 2.798 | 102.5 | 57.5 | .0214 | 1500 | 1232 | 84.7 | ---- | |
| 944 | 5 | 15.0 | 272 | .745 | 2.790 | 102.8 | 57.8 | .0215 | 1525 | 1253 | 85.7 | 19.5 | |
| 945 | | 15.0 | 268 | .750 | 2.809 | 102.9 | 61.6 | .0228 | 1585 | 1317 | 85.5 | ---- | |
| 946 | | 15.1 | 262 | | | 101.4 | 65.5 | .0242 | 1640 | 1378 | 84.7 | ---- | |
| 947 | | 15.0 | 267 | | | 102.7 | 68.4 | .0253 | 1670 | 1403 | 83.0 | ---- | |
| 948 | | 15.0 | 270 | | | 103.2 | 70.5 | .0261 | 1700 | 1430 | 82.5 | ---- | |
| 949 | 10 | 15.1 | 272 | .745 | 2.790 | 102.1 | 70.8 | .0264 | 1710 | 1438 | 82.1 | 19.7 | (e) |
| 950 | 0 | 8.0 | 268 | .396 | 1.483 | 101.9 | 38.7 | .0272 | 1300 | 1032 | 56.1 | 12.2 | |
| 951 | | | 274 | .397 | 1.487 | 103.0 | 34.9 | .0245 | 1310 | 1036 | 62.3 | ---- | |
| 952 | | | 264 | .396 | 1.483 | 101.3 | 31.4 | .0220 | 1240 | 976 | 64.3 | ---- | |
| 953 | | | 264 | .398 | 1.491 | 101.8 | 29.3 | .0204 | 1190 | 926 | 65.2 | ---- | |
| 954 | | | ---- | .396 | 1.483 | ---- | 26.3 | .0185 | ---- | ---- | ---- | ---- | (d) |
| 955 | | | 269 | .396 | 1.483 | 102.0 | 37.1 | .0260 | 1300 | 1031 | 58.3 | 12.3 | |
| 957 | 4 | 8.0 | 273 | .398 | 1.491 | 103.1 | 44.7 | .0312 | 1400 | 1127 | 54.2 | 11.4 | (f) |
| 958 | | 7.9 | ---- | .398 | 1.491 | ---- | 40.7 | .0284 | 1300[c] | ---- | ---- | ---- | (d) |
| 960 | | ---- | ---- | ---- | ---- | ---- | 50.2 | .0351 | 1350[c] | ---- | ---- | ---- | (d) |
| 961 | | 8.1 | 270 | .397 | 1.487 | 101.1 | 46.8 | .0328 | 1410 | 1140 | 52.6 | ---- | |
| 962 | | 8.0 | 273 | .396 | 1.483 | 102.6 | 41.5 | .0292 | 1370 | 1097 | 56.2 | ---- | |

[a]Near blow-out.
[b]Rough burning.
[c]Approximate temperature just before blow-out.
[d]Blow-out.
[e]Noisy combustion.
[f]Somewhat unstable.

3553

CD-3 back

TABLE II. - Continued. EXPERIMENTAL DATA

| Run | Combustor crank setting | Combustor-inlet total pressure, $P_1$, in. Hg abs | Combustor-inlet total temperature, $T_1$, °F | Air-flow rate, lb/sec | Air-flow rate per unit area, lb/(sec)(sq ft) | Combustor reference velocity, $V_r$, ft/sec | Fuel-flow rate, lb/hr | Fuel air ratio | Mean combustor-outlet total temperature, °F | Mean combustor temperature rise, °F | Combustion efficiency, percent | Total pressure-loss through combustor, in. water | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model 25 | | | | | | | | | | | | | |
| | 0 | 8.0 | 270 | 0.396 | 1.483 | 102.1 | 0 | 0 | ---- | 0 | ---- | 9.9 | (a) |
| | 0 | 15.0 | 272 | .742 | 2.779 | 102.4 | 0 | 0 | ---- | 0 | ---- | 16.9 | (a) |
| 990 | | 8.0 | 271 | .395 | 1.479 | 102.0 | 44.4 | 0.0312 | 1100 | 829 | 39.3 | 12.0 | |
| 994 | | | 275 | .395 | 1.479 | 102.6 | 29.3 | .0206 | 1055 | 780 | 54.3 | 11.6 | |
| 995 | | | 267 | .394 | 1.476 | 101.2 | 26.5 | .0187 | 1010 | 743 | 56.5 | ---- | |
| 996 | | | 272 | | | 101.9 | 23.8 | .0168 | 955 | 683 | 57.5 | ---- | |
| 997 | | | 268 | | | 101.4 | 22.0 | .0155 | 875 | 607 | 54.8 | ---- | |
| 998 | | | 270 | | | 101.6 | 19.5 | .0138 | 820 | 550 | 55.5 | ---- | |
| 999 | | | 270 | | | 101.6 | 42.0 | .0297 | 1120 | 850 | 42.2 | 11.8 | |
| 1001 | 5 | 8.1 | 274 | .393 | 1.472 | 100.7 | 45.8 | .0324 | 1360 | 1086 | 50.4 | 10.5 | |
| 1007 | 5 | 8.0 | 268 | .395 | 1.479 | 101.6 | 26.5 | .0187 | 960 | 692 | 52.7 | 9.5 | |
| 1010 | 10 | 8.0 | 266 | .395 | 1.479 | 101.3 | 43.4 | .0306 | 1320 | 1054 | 51.5 | 10.3 | |
| 1011 | | | 266 | .394 | 1.476 | 101.1 | 40.9 | .0288 | 1305 | 1039 | 53.5 | ---- | |
| 1012 | | | 269 | | | 101.5 | 36.0 | .0254 | 1220 | 951 | 54.8 | ---- | (b) |
| 1013 | | | 263 | | | 100.7 | 45.5 | .0321 | 1360 | 1097 | 51.4 | 10.3 | |
| 1014 | | | 270 | | | 101.6 | 49.1 | .0347 | 1460 | 1190 | 52.2 | ---- | |
| 1015 | | | 271 | .395 | 1.479 | 102.0 | 54.1 | .0380 | 1505 | 1234 | 49.8 | ---- | (c) |
| 1016 | 0 | 14.9 | 269 | .735 | 2.753 | 101.7 | 48.1 | .0182 | 1210 | 941 | 74.2 | 19.5 | |
| 1017 | | 14.9 | 269 | .733 | 2.745 | 101.4 | 44.4 | .0169 | 1155 | 886 | 75.0 | ---- | |
| 1018 | | 15.0 | 272 | .735 | 2.753 | 101.4 | 40.4 | .0153 | 1075 | 803 | 74.4 | ---- | (b) |
| 1019 | | | 268 | .737 | 2.760 | 101.1 | 35.8 | .0135 | 985 | 717 | 74.4 | ---- | (b) |
| 1020 | | | 269 | .740 | 2.772 | 101.7 | 32.5 | .0122 | 915 | 646 | 73.5 | ---- | (b) |
| 1021 | | | 269 | .735 | 2.753 | 101.0 | 46.8 | .0177 | 1190 | 921 | 74.6 | ---- | |
| 1022 | | | 269 | .735 | 2.753 | 101.0 | 52.6 | .0199 | 1285 | 1016 | 74.0 | 19.6 | |
| 1025 | 5 | 15.0 | 267 | .737 | 2.760 | 101.0 | 64.7 | .0243 | 1545 | 1278 | 78.0 | 18.1 | |
| 1026 | | | 264 | .745 | 3.790 | 101.6 | 58.9 | .0220 | 1445 | 1181 | 79.0 | ---- | |
| 1027 | | | 268 | .737 | 2.760 | 101.1 | 53.6 | .0202 | 1340 | 1072 | 77.2 | ---- | |
| 1028 | | | 270 | .735 | 2.753 | 101.1 | 48.4 | .0183 | 1240 | 970 | 76.4 | ---- | |
| 1029 | | | 267 | .742 | 2.779 | 101.7 | 44.9 | .0168 | 1145 | 878 | 74.4 | ---- | |
| 1031 | | | 273 | .740 | 2.772 | 102.2 | 70.0 | .0263 | 1630 | 1357 | 77.6 | 18.6 | |
| 1033 | 10 | 15.0 | 269 | .740 | 2.772 | 101.7 | 77.9 | .0292 | 1795 | 1526 | 79.6 | 18.0 | |
| 1034 | | 15.0 | 263 | | | 100.8 | 81.3 | .0305 | 1840 | 1577 | 79.2 | ---- | |
| 1035 | | 14.9 | 268 | | | 102.2 | 73.4 | .0276 | 1720 | 1452 | 79.6 | ---- | |
| 1036 | | 15.0 | 268 | | | 101.5 | 67.1 | .0252 | 1630 | 1362 | 81.0 | ---- | |
| 1037 | | 14.9 | 271 | | | 102.6 | 61.3 | .0230 | 1510 | 1239 | 79.5 | ---- | |
| 1038 | | 15.0 | 272 | .742 | 2.779 | 102.4 | 55.2 | .0206 | 1320 | 1098 | 77.5 | ---- | |
| Model 26 | | | | | | | | | | | | | |
| | 0 | 15.0 | 269 | 0.741 | 2.775 | 101.8 | 0 | 0 | ---- | 0 | ---- | 16.7 | (a) |
| | | 15.0 | 269 | .928 | 3.476 | 127.5 | | | ---- | | ---- | 30.0 | (a) |
| | | 8.0 | 279 | .397 | 1.487 | 103.7 | | | ---- | | ---- | 10.1 | (a) |
| 1042 | 2.5 | 8.0 | 272 | .397 | 1.487 | 102.7 | 39.5 | 0.0277 | 1500 | 1228 | 66.4 | 12.4 | (d) |
| 1043 | | 7.9 | 277 | | | 104.7 | 32.7 | .0228 | 1370 | 1093 | 70.1 | ---- | (d) |
| 1044 | | 8.0 | 275 | | | 103.1 | 29.8 | .0209 | 1325 | 1050 | 73.1 | ---- | (d) |
| 1045 | | | 272 | | | 102.7 | 27.1 | .0190 | 1220 | 948 | 72.0 | 11.3 | (d) |
| 1050 | | | 266 | | | 101.8 | 44.7 | .0313 | 1520 | 1254 | 60.6 | ---- | (d) |
| 1051 | | | 274 | | | 103.0 | 47.5 | .0334 | 1480 | 1206 | 55.0 | ---- | (d) |
| 1054 | 0 | 14.9 | 264 | .742 | 2.779 | 101.9 | 48.3 | .0181 | 1330 | 1066 | 85.2 | ---- | |
| 1055 | | 15.0 | 266 | .742 | 2.779 | 101.5 | 44.7 | .0168 | 1270 | 1004 | 86.0 | ---- | |
| 1056 | | 14.9 | 273 | .740 | 2.772 | 102.9 | 40.7 | .0153 | 1185 | 912 | 84.8 | ---- | (b) |
| 1057 | | 15.0 | 273 | .740 | 2.772 | 102.2 | 37.1 | .0139 | 1130 | 857 | 87.0 | ---- | (b) |
| 1058 | | | 264 | .745 | 2.790 | 101.6 | 32.5 | .0121 | 1020 | 756 | 87.0 | ---- | (b) |
| 1059 | | | 262 | .740 | 2.772 | 100.7 | 29.8 | .0112 | 975 | 713 | 88.5 | 19.3 | (b) |
| 1060 | 5 | 15.0 | 278 | .742 | 2.779 | 103.2 | 53.6 | .0201 | 1430 | 1152 | 84.0 | 21.0 | |
| 1061 | | | 268 | .740 | 2.772 | 101.5 | 51.2 | .0192 | 1390 | 1122 | 84.8 | ---- | |
| 1062 | | | 280 | .742 | 2.779 | 103.5 | 47.5 | .0178 | 1330 | 1050 | 85.4 | ---- | |
| 1063 | | 15.1 | 266 | | | 100.8 | 57.3 | .0214 | 1510 | 1244 | 85.3 | ---- | |
| 1064 | | 15.0 | 267 | | | 101.7 | 61.0 | .0228 | 1570 | 1303 | 84.5 | ---- | |
| 1065 | | | 265 | | | 101.4 | 66.0 | .0247 | 1640 | 1375 | 83.2 | ---- | |
| 1066 | | | 270 | .740 | 2.772 | 101.8 | 71.6 | .0269 | 1720 | 1450 | 81.5 | ---- | |
| 1071 | 0 | 15.0 | 266 | .973 | 3.644 | 133.1 | 43.1 | .0123 | 1025 | 759 | 86.0 | ---- | |
| 1072 | | 15.0 | 268 | .965 | 3.614 | 132.4 | 39.0 | .0112 | 965 | 697 | 86.2 | ---- | |
| 1073 | | 15.1 | 270 | .980 | 3.670 | 133.9 | 30.6 | .0087 | 800 | 530 | 83.6 | ---- | |
| 1074 | 1.5 | 15.0 | 280 | .970 | 3.633 | 135.3 | 58.7 | .0168 | 1270 | 990 | 84.6 | ---- | |
| 1075 | | | 280 | .980 | 3.670 | 136.6 | 51.8 | .0147 | 1185 | 905 | 87.5 | ---- | |
| 1076 | | | 260 | .980 | 3.670 | 133.0 | 45.2 | .0128 | 1060 | 800 | 87.5 | ---- | |
| 1077 | | | 278 | .970 | 3.633 | 134.9 | 64.9 | .0186 | 1375 | 1097 | 85.6 | ---- | |
| 1078 | | 15.1 | 264 | .975 | 3.652 | 132.2 | 71.6 | .0204 | 1435 | 1171 | 83.8 | ---- | |
| 1079 | | 15.0 | 265 | .970 | 3.633 | 132.5 | 76.6 | .0219 | 1495 | 1230 | 82.6 | ---- | |

[a]No burning.
[b]Rough burning
[c]Blow-out.
[d]Very rough burning.

3553

TABLE II. - Continued. EXPERIMENTAL DATA

| Run | Combustor crank setting | Combustor-inlet total pressure, $P_1$, in. Hg abs | Combustor-inlet total temperature, $T_1$, °F | Air-flow rate, lb/sec | Air-flow rate per unit area, lb/(sec)(sq ft) | Combustor reference velocity, $V_r$, ft/sec | Fuel-flow rate, lb/hr | Fuel-air ratio | Mean combustor-outlet total temperature, °F | Mean combustor temperature rise, °F | Combustion efficiency, percent | Total pressure-loss through combustor, in. water | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model 29 | | | | | | | | | | | | | |
| | 0 | 8.0 | 271 | 0.398 | 1.491 | 102.8 | 0 | 0 | ---- | 0 | ---- | 9.7 | (a) |
| | | 15.0 | 266 | .748 | 2.801 | 102.3 | | | ---- | | ---- | 16.8 | (a) |
| | | 15.0 | 263 | .965 | 3.614 | 131.5 | | | ---- | | ---- | 29.0 | (a) |
| 1179 | | 8.0 | 266 | .397 | 1.487 | 101.8 | 35.2 | 0.0246 | 1425 | 1159 | 69.6 | 12.5 | |
| 1180 | | | 267 | .395 | 1.479 | 101.4 | 30.6 | .0215 | 1335 | 1068 | 72.3 | ---- | |
| 1181 | | | 264 | .397 | 1.487 | 101.6 | 27.1 | .0189 | 1250 | 986 | 74.9 | ---- | |
| 1182 | | | 267 | | | 102.0 | 22.0 | .0154 | 1110 | 843 | 77.5 | ---- | |
| 1183 | | | 268 | | | 102.1 | 18.4 | .0129 | 1015 | 747 | 81.2 | 11.5 | |
| 1184 | | | 268 | | | 102.1 | 24.9 | .0174 | 1195 | 927 | 76.1 | ---- | |
| 1185 | | | 266 | | | 101.8 | 36.8 | .0257 | 1455 | 1189 | 68.5 | ---- | (b) |
| 1186 | | | 269 | | | 102.3 | 42.0 | .0294 | 1445 | 1176 | 59.9 | ---- | (c) |
| 1187 | 2.5 | 8.1 | 268 | .398 | 1.491 | 101.1 | 33.3 | .0232 | 1300 | 1032 | 64.8 | 11.7 | |
| 1196 | 0 | 15.0 | 264 | .737 | 2.760 | 100.5 | 41.8 | .0158 | 1215 | 951 | 86.0 | 19.4 | |
| 1197 | | | 264 | .739 | 2.768 | 100.8 | 37.7 | .0142 | 1135 | 871 | 86.7 | ---- | (b) |
| 1198 | | | 265 | .740 | 2.772 | 101.1 | 34.4 | .0129 | 1070 | 805 | 87.4 | ---- | |
| 1199 | | | 267 | .742 | 2.779 | 101.7 | 29.8 | .0112 | 975 | 708 | 88.1 | ---- | |
| 1200 | | 15.1 | 266 | .745 | 2.790 | 101.2 | 24.9 | .0093 | 880 | 614 | 90.9 | ---- | |
| 1201 | | 15.0 | 263 | .743 | 2.783 | 101.2 | 20.9 | .0078 | 780 | 517 | 90.0 | ---- | |
| 1202 | | | 266 | .743 | 2.783 | 101.7 | 32.7 | .0122 | 1035 | 769 | 87.9 | ---- | |
| 1203 | | | 266 | .742 | 2.779 | 101.5 | 45.2 | .0169 | 1270 | 1004 | 85.1 | ---- | |
| 1204 | | | 264 | | | 101.2 | 48.6 | .0182 | 1335 | 1071 | 85.0 | ---- | |
| 1205 | | | 266 | | | 101.5 | 53.1 | .0198 | 14.0 | 1144 | 83.8 | 20.7 | |
| 1217 | 5 | 15.0 | 266 | .739 | 2.768 | 101.1 | 74.4 | .0280 | 1720 | 1454 | 78.8 | 20.0 | (b) |
| 1218 | 7.5 | 15.0 | 264 | .742 | 2.779 | 101.2 | 74.4 | .0279 | 1780 | 1516 | 82.4 | ---- | |
| 1219 | | | 266 | .742 | 2.779 | 101.5 | 79.5 | .0298 | 1875 | 1609 | 82.9 | ---- | (b) |
| 1220 | | | 263 | .745 | 2.790 | 101.5 | 66.5 | .0248 | 1680 | 1417 | 85.6 | ---- | (d) |
| 1221 | | | 266 | | | 101.9 | 59.4 | .0222 | 1550 | 1284 | 85.6 | ---- | (d) |
| 1223 | | | 264 | | | 101.6 | 59.2 | .0221 | 1530 | 1266 | 84.6 | ---- | |
| 1224 | | | 266 | .742 | 2.779 | 101.5 | 54.4 | .0204 | 1420 | 1154 | 82.8 | 17.9 | |
| 1225 | | | 265 | .741 | 2.775 | 101.2 | 69.5 | .0261 | 1690 | 1425 | 82.3 | ---- | |
| 1226 | | | 264 | .742 | 2.779 | 101.2 | 78.0 | .0292 | 1860 | 1596 | 83.5 | ---- | |
| 1228 | 0 | 15.0 | 268 | .964 | 3.610 | 132.2 | 48.1 | .0139 | 1120 | 852 | 86.6 | 34.5 | |
| 1229 | | | 264 | .963 | 3.607 | 131.4 | 44.1 | .0127 | 1055 | 791 | 87.0 | ---- | |
| 1230 | | | 263 | .964 | 3.610 | 131.3 | 40.4 | .0116 | 995 | 732 | 87.6 | ---- | |
| 1231 | | | 262 | .963 | 3.607 | 131.0 | 36.0 | .0104 | 930 | 668 | 88.9 | ---- | |
| 1232 | | | 267 | | | 131.9 | 31.7 | .0091 | 860 | 593 | 89.4 | ---- | (b) |
| 1233 | | | 265 | | | 131.6 | 27.8 | .0081 | 800 | 535 | 90.1 | ---- | (b) |
| 1234 | | 14.9 | 262 | .964 | 3.610 | 132.0 | 23.5 | .0068 | 720 | 458 | 91.0 | ---- | |
| 1235 | | 15.0 | 266 | .963 | 3.607 | 131.8 | 50.7 | .0147 | 1155 | 889 | 85.6 | ---- | (b) |
| 1236 | | | 265 | | | 131.6 | 57.4 | .0166 | 1250 | 985 | 85.0 | ---- | |
| 1237 | | | 266 | | | 131.8 | 60.5 | .0174 | 1290 | 1024 | 84.4 | ---- | |
| 1238 | | | 262 | | | 131.0 | 63.4 | .0183 | 1315 | 1053 | 83.2 | ---- | (b) |
| 1240 | 5 | 15.0 | 264 | .963 | 3.607 | 131.4 | 67.1 | .0193 | 1370 | 1106 | 83.0 | 31.8 | |
| 1241 | 5 | 15.0 | 267 | .963 | 3.607 | 131.9 | 72.6 | .0209 | 1445 | 1178 | 82.4 | ---- | |
| 1244 | 10 | 15.1 | 266 | .969 | 3.629 | 131.7 | 81.8 | .0234 | 1575 | 1309 | 82.7 | ---- | |
| 1245 | 10 | 15.0 | 262 | .967 | 3.622 | 131.6 | 85.8 | .0246 | 1650 | 1388 | 84.0 | ---- | (b) |
| 1248 | 15 | 15.0 | 266 | .963 | 3.607 | 131.8 | 94.0 | .0271 | 1760 | 1494 | 83.4 | ---- | |
| 1249 | | | 264 | | | 131.4 | 101.8 | .0294 | 1670 | 1406 | 72.5 | ---- | (d) |
| 1250 | | | 267 | | | 131.9 | 85.2 | .0246 | 1650 | 1383 | 84.0 | ---- | (d) |
| Model 34 | | | | | | | | | | | | | |
| 1327 | 5 | 8.0 | 267 | 0.397 | 1.487 | 102.0 | 29.5 | 0.0207 | 1330 | 1063 | 74.8 | 13.2 | |
| 1328 | | | 270 | | | 102.4 | 33.0 | .0231 | 1380 | 1110 | 70.6 | ---- | |
| 1329 | | | 274 | | | 103.0 | 35.4 | .0248 | 1436 | 1161 | 69.4 | ---- | (b) |
| 1330 | | | 270 | | | 102.4 | 37.9 | .0266 | 1535 | 1265 | 71.3 | ---- | |
| 1331 | | | 269 | | | 102.3 | 42.0 | .0294 | 1640 | 1371 | 70.5 | ---- | |
| 1332 | | 8.1 | 262 | | | 100.0 | 43.9 | .0308 | 1600[e] | 1338 | 66.0 | ---- | (c) |
| 1334 | | 8.0 | 262 | | | 101.3 | 27.1 | .0190 | 1270 | 1008 | 76.5 | 13.0 | |
| 1335 | | 8.0 | 269 | | | 102.3 | 23.6 | .0165 | 1160 | 891 | 76.8 | ---- | |
| 1336 | | ---- | 262 | | | ---- | 20.6 | .0144 | 1000[e] | 738 | 71.8 | ---- | (c) |
| 1338 | | 8.0 | 271 | | | 102.5 | 24.6 | .0172 | 1190 | 919 | 76.2 | ---- | |
| 1339 | | 8.0 | 266 | | | 101.8 | 36.0 | .0252 | 1480 | 1214 | 71.5 | ---- | |
| 1340 | 10 | 8.0 | 266 | .397 | 1.487 | 101.8 | 39.2 | .0274 | 1585 | 1319 | 72.1 | ---- | |
| 1341 | 10 | 8.1 | 264 | .397 | 1.487 | 100.3 | 43.6 | .0306 | 1670[e] | 1406 | 69.8 | ---- | (c) |
| 1342 | 0 | 15.0 | 267 | .960 | 3.596 | 131.5 | 47.6 | .0138 | 1120 | 853 | 87.4 | ---- | |
| 1343 | | 15.1 | 269 | .975 | 3.652 | 133.1 | 42.6 | .0121 | 1030 | 761 | 87.6 | ---- | |
| 1344 | | 15.0 | 274 | .967 | 3.622 | 133.8 | 38.2 | .0110 | 970 | 696 | 88.1 | ---- | |
| 1345 | | | 273 | .960 | 3.596 | 132.6 | 34.7 | .0100 | 905 | 632 | 86.9 | 37.8 | |
| 1346 | | | 272 | .972 | 3.640 | 134.1 | 30.0 | .0086 | 820 | 548 | 87.4 | ---- | |
| 1347 | | | 268 | .972 | 3.640 | 133.3 | 24.9 | .0071 | 740 | 472 | 89.9 | ---- | |
| 1348 | | | 274 | .967 | 3.622 | 133.8 | 18.7 | .0054 | 640 | 366 | 90.9 | 35.6 | |
| 1349 | | | 261 | .975 | 3.652 | 132.5 | 46.5 | .0132 | 1090 | 829 | 86.2 | ---- | |
| 1350 | | | 261 | .975 | 3.652 | 132.5 | 53.1 | .0151 | 1195 | 934 | 87.7 | ---- | |
| 1351 | | | ---- | .962 | 3.603 | ---- | 57.8 | .0167 | 1260 | ---- | 85.6 | ---- | (b,f) |

[a]No burning.
[b]Rough burning.
[c]Blow-out.
[d]Very rough burning.
[e]Approximate temperature just before blow-out.
[f]Near blow-out.

3553

TABLE II. - Concluded. EXPERIMENTAL DATA

| Run | Combustor crank setting | Combustor-inlet total pressure, $P_i$, in. Hg abs | Combustor-inlet total temperature, $T_i$, °F | Air-flow rate, lb/sec | Air-flow rate per unit area, lb/(sec)(sq ft) | Combustor reference velocity, $V_r$, ft/sec | Fuel-flow rate, lb/hr | Fuel-air ratio | Mean combustor-outlet total temperature, °F | Mean combustor temperature rise, °F | Combustion efficiency, percent | Total pressure-loss through combustor, in. water | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model 41 | | | | | | | | | | | | | |
| 1459 | 0 | 8.0 | 264 | 0.391 | 1.464 | 99.99 | 29.0 | 0.0206 | 1280 | 1026 | 72.3 | 11.2 | |
| 1460 | | | 272 | .390 | 1.461 | 100.9 | 34.7 | .0247 | 1435 | 1163 | 69.6 | ---- | |
| 1461 | | | 272 | .394 | 1.476 | 101.9 | 38.1 | .0269 | 1485 | 1213 | 67.4 | ---- | |
| 1462 | | | 270 | .394 | 1.476 | 101.6 | 30.5 | .0214 | 1325 | 1055 | 72.0 | 11.4 | |
| 1463 | | | 268 | .393 | 1.472 | 101.1 | 26.5 | .0188 | 1210 | 942 | 72.3 | ---- | (a,b) |
| 1464 | | 15.0 | 269 | .967 | 3.622 | 132.9 | 43.4 | .0125 | 1045 | 776 | 87.1 | 32.2 | |
| 1465 | | | 268 | .967 | 3.622 | 132.7 | 38.1 | .0109 | 950 | 682 | 86.7 | ---- | |
| 1466 | | | 265 | .962 | 3.603 | 131.4 | 35.7 | .0103 | 890 | 625 | 85.6 | ---- | (b) |
| 1467 | | | 268 | .967 | 3.622 | 132.7 | 48.3 | .0139 | 1125 | 857 | 87.0 | ---- | |
| 1468 | | | 262 | .969 | 3.629 | 131.8 | 51.5 | .0148 | 1170 | 908 | 87.3 | ---- | |
| 1469 | | | 263 | | | 132.0 | 55.7 | .0160 | 1215 | 952 | 85.0 | 34.6 | |
| 1470 | | | 262 | | | 131.8 | 60.5 | .0173 | 1250 | 988 | 81.9 | ---- | |
| 1471 | | | 267 | | | 132.7 | 67.3 | .0193 | 1260 | 993 | 74.1 | ---- | (b) |
| 1472 | | | ---- | | | ---- | 29.2 | .0084 | ---- | ---- | ---- | ---- | (c) |
| Model 42 | | | | | | | | | | | | | |
| 1482 | 0 | 15.0 | 256 | 0.970 | 3.633 | 130.9 | 60.0 | 0.0172 | 1240 | 984 | 82.0 | 34.9 | (d) |
| 1483 | | 15.1 | 270 | .975 | 3.652 | 133.2 | 65.5 | .0186 | 1295 | 1025 | 79.4 | ---- | |
| 1484 | | 15.0 | 264 | .972 | 3.640 | 132.6 | 71.3 | .0204 | 1360 | 1096 | 78.1 | 37.0 | |
| 1485 | | 15.0 | 267 | .975 | 3.652 | 133.6 | 76.6 | .0218 | 1400 | 1133 | 76.0 | ---- | (b) |
| 1486 | | 15.1 | 272 | .974 | 3.648 | 133.5 | 79.5 | .0227 | 1450 | 1178 | 76.5 | ---- | (b) |
| 1487 | | 15.0 | 280 | .965 | 3.614 | 134.6 | 85.6 | .0246 | 1470 | 1190 | 71.6 | ---- | (b) |
| 1488 | | | 266 | .975 | 3.652 | 133.4 | 89.4 | .0255 | 1390 | 1124 | 65.3 | 38.3 | (d) |
| 1489 | | | 260 | .975 | 3.652 | 132.3 | 56.3 | .0161 | ---- | ---- | ---- | ---- | (c) |
| 1490 | | | 267 | .735 | 2.755 | 100.7 | 44.2 | .0167 | 1285 | 1018 | 87.5 | 20.1 | |
| 1491 | | | 266 | .740 | 2.772 | 101.3 | 49.4 | .0186 | 1370 | 1104 | 86.1 | ---- | (b) |
| 1492 | | | 270 | .745 | 2.790 | 102.5 | 55.0 | .0205 | 1450 | 1180 | 84.3 | ---- | (b) |
| 1493 | | | 266 | .742 | 2.779 | 101.5 | 60.2 | .0225 | 1540 | 1274 | 83.5 | ---- | |
| 1494 | | 15.1 | 260 | .745 | 2.790 | 100.4 | 66.5 | .0248 | 1630 | 1370 | 82.0 | ---- | |
| 1495 | | 15.0 | 255 | .742 | 2.779 | 99.97 | 72.6 | .0272 | 1720 | 1465 | 81.3 | 22.3 | |
| 1496 | | | 268 | .743 | 2.783 | 101.9 | 77.0 | .0288 | 1790 | 1522 | 80.6 | ---- | |
| 1497 | | | 256 | .742 | 2.779 | 100.1 | 57.8 | .0216 | 1505 | 1249 | 84.9 | ---- | |
| 1498 | | | 258 | .750 | 2.809 | 101.5 | 35.2 | .0131 | ---- | ---- | ---- | ---- | (c) |
| Model 46 | | | | | | | | | | | | | |
| 1555 | 0 | 8.1 | 265 | 0.393 | 1.472 | 99.44 | 34.9 | 0.0247 | 1420 | 1155 | 69.0 | ---- | |
| 1556 | | 8.0 | 268 | | | 101.1 | 38.2 | .0270 | 1500 | 1232 | 68.0 | ---- | (b) |
| 1557 | | | 274 | | | 101.9 | 41.5 | .0294 | 1580 | 1306 | 67.2 | ---- | (b) |
| 1558 | | | 269 | | | 101.2 | 45.0 | .0318 | 1665 | 1396 | 67.0 | ---- | (b) |
| 1560 | | | 273 | | | 101.8 | 32.5 | .0250 | 1355 | 1082 | 69.1 | ---- | |
| 1561 | | | 273 | .392 | 1.468 | 101.5 | 29.5 | .0209 | 1260 | 987 | 68.4 | ---- | |
| 1562 | | | 270 | .392 | 1.468 | 101.1 | 26.9 | .0190 | 1180 | 910 | 68.5 | 10.9 | |
| 1563 | | | 266 | .393 | 1.472 | 100.8 | 23.0 | .0162 | 1095 | 829 | 72.2 | ---- | |
| 1564 | | 7.9 | 265 | .392 | 1.468 | 101.7 | 18.9 | .0134 | 960 | 695 | 72.3 | ---- | |
| 1565 | | 8.0 | 268 | .393 | 1.472 | 101.1 | 19.7 | .0139 | 960 | 692 | 69.5 | ---- | |
| 1566 | | | 269 | .393 | 1.472 | 101.2 | 17.5 | .0124 | 900 | 631 | 70.8 | ---- | |
| 1567 | | | 270 | .392 | 1.468 | 101.1 | 15.8 | .0112 | 850 | 580 | 71.4 | 10.3 | |
| 1568 | | | 271 | | | 101.2 | 13.8 | .0098 | 760 | 489 | 68.3 | ---- | |
| 1569 | | | 270 | | | 101.1 | 11.8 | .0084 | 660 | 390 | 63.2 | ---- | (b) |
| 1570 | | | 268 | .393 | 1.472 | 101.1 | 11.2 | .0079 | 605 | 337 | 57.6 | ---- | (b) |
| 1571 | | | 268 | .392 | 1.468 | 100.8 | 10.0 | .0071 | 510 | 242 | 45.9 | ---- | (b) |
| 1576 | 2.5 | 8.05 | 268 | .392 | 1.468 | 100.2 | 49.4 | .0350 | 1740 | 1472 | 64.9 | ---- | (b) |
| 1578 | 5 | 8.05 | 263 | .390 | 1.461 | 99.03 | 53.9 | .0384 | 1750 | 1487 | 60.3 | ---- | (d) |
| 1579 | 5 | 8.0 | 266 | .391 | 1.464 | 100.3 | 58.1 | .0412 | 1860 | 1594 | 60.8 | ---- | (c) |
| 1606 | 0 | 15.0 | 268 | .983 | 3.682 | 134.9 | 50.4 | .0142 | 1075 | 807 | 79.8 | ---- | |
| 1607 | | | 265 | .995 | 3.727 | 136.0 | 57.5 | .0161 | 1170 | 905 | 80.5 | ---- | |
| 1608 | | | 268 | 1.000 | 3.745 | 137.2 | 64.5 | .0179 | 1245 | 977 | 78.2 | ---- | |
| 1609 | | | 267 | 1.050 | 3.933 | 143.9 | 74.7 | .0198 | 1395 | 1128 | 83.0 | ---- | |
| 1610 | | | 267 | .993 | 3.719 | 136.0 | 80.5 | .0225 | 1505 | 1238 | 80.9 | ---- | |
| 1611 | | | 264 | .997 | 3.734 | 136.0 | 88.7 | .0247 | 1555 | 1291 | 77.7 | ---- | (b) |
| 1612a | | | 267 | .990 | 3.708 | 135.6 | 94.6 | .0265 | 1645 | 1378 | 77.9 | ---- | (a) |
| 1612b | | | ---- | .990 | 3.708 | ---- | 101.7 | .0285 | ---- | ---- | ---- | ---- | (c) |
| 1613 | | 14.9 | 265 | .987 | 3.697 | 135.8 | 48.4 | .0136 | 1035 | 770 | 79.3 | ---- | |
| 1614 | | 15.0 | 266 | .990 | 3.708 | 135.4 | 43.9 | .0123 | 965 | 689 | 79.0 | ---- | |
| 1615 | | | 263 | | | 134.9 | 38.2 | .0107 | 905 | 642 | 82.5 | ---- | |
| 1616 | | | 267 | | | 135.6 | 32.8 | .0092 | 830 | 563 | 83.8 | ---- | (b) |
| 1617 | | | 267 | .992 | 3.715 | 135.9 | 27.1 | .0076 | 745 | 478 | 85.5 | ---- | |
| 1618 | | 14.8 | ---- | .993 | 3.719 | ---- | 20.0 | .0056 | ---- | ---- | ---- | ---- | (c) |
| 1619 | | 15.0 | 268 | .782 | 2.929 | 107.3 | 38.4 | .0136 | 1025 | 757 | 77.8 | ---- | (b) |
| 1620 | | | 265 | .782 | 2.929 | 106.8 | 43.6 | .0155 | 1115 | 850 | 77.6 | ---- | (b) |
| 1621 | | | 265 | .785 | 2.940 | 107.2 | 48.9 | .0173 | 1205 | 940 | 77.9 | ---- | (b) |
| 1622 | | | 269 | .783 | 2.933 | 107.6 | 54.7 | .0194 | 1330 | 1061 | 79.1 | ---- | (b) |
| 1623 | | | 267 | .780 | 2.921 | 106.8 | 61.0 | .0217 | 1460 | 1193 | 80.5 | 19.9 | (b) |
| 1624 | | | 268 | | | 107.0 | 66.5 | .0237 | 1580 | 1312 | 82.4 | ---- | (b) |
| 1625 | | | 268 | | | 107.0 | 71.3 | .0254 | 1655 | 1387 | 81.6 | ---- | (b) |
| 1626 | | | 263 | | | 106.3 | 76.5 | .0272 | 1750 | 1487 | 82.6 | ---- | (b) |
| 1627 | | | 268 | .782 | 2.929 | 107.3 | 78.9 | .0280 | 1805 | 1537 | 85.4 | ---- | (b) |
| 1628 | 5 | 14.9 | 268 | .780 | 2.921 | 107.7 | 79.2 | .0282 | 1780 | 1512 | 81.4 | ---- | (b) |
| 1629 | 0 | 15.0 | 265 | .782 | 2.929 | 106.8 | 37.4 | .0133 | 1050 | 785 | 82.7 | ---- | (b) |
| 1630 | | 15.0 | 263 | .780 | 2.921 | 106.3 | 31.7 | .0113 | 960 | 697 | 85.6 | ---- | (b) |
| 1631 | | 14.9 | 268 | .778 | 2.914 | 107.5 | 26.8 | .0096 | 895 | 627 | 90.1 | ---- | (b) |
| 1632 | | 15.0 | 268 | .782 | 2.929 | 107.3 | 21.7 | .0077 | 760 | 492 | 88.7 | ---- | |
| 1633 | | | 269 | .783 | 2.933 | 107.6 | 22.1 | .0079 | 755 | 486 | 83.6 | ---- | |
| 1634 | | | 268 | .765 | 2.865 | 104.9 | 19.6 | .0071 | 700 | 432 | 82.3 | ---- | |
| 1635 | | | 264 | .780 | 2.921 | 106.4 | 19.4 | .0069 | 670 | 406 | 79.3 | ---- | |
| 1636 | | | 264 | .775 | 2.903 | 105.7 | 17.6 | .0063 | 575 | 311 | 66.0 | ---- | (b) |
| 1637 | | | ---- | .775 | 2.903 | ---- | 16.1 | .0058 | ---- | ---- | ---- | ---- | (c) |

[a]Near blow-out.
[b]Rough burning.
[c]Blow-out.
[d]Very rough burning.

[redacted]

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TABLE III. - DATA OF COMBUSTORS OF DIFFERENT SIZE

| Reference | Combustor | Combustor type: Production | Combustor type: Experimental | Dimensions: Maximum combustor cross-sectional area, sq in. | Dimensions: Hydraulic radius, in. | Combustion efficiency, percent: $V_r/P_iT_i = 100\times10^{-6}$, From ref. 12 (a) | $V_r/P_iT_i = 100\times10^{-6}$, Temperature rise, 680° F | $V_r/P_iT_i = 248\times10^{-6}$, From ref. 12 (a) | $V_r/P_iT_i = 248\times10^{-6}$, Temperature rise, 680° F | $V_r/P_iT_i = 248\times10^{-6}$, Temperature rise, 1180° F |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | A | X | | 234.4 | 0.65 | 64.0 | | (b) | | |
| | B | X | | 234.4 | .76 | 64.0 | | (b) | | |
| | C | X | | 74.8 | 1.13 | 69.0 | | (b) | | |
| | D | | X | 74.8 | 1.13 | 79.5 | | (b) | | |
| | E | X | | 58.5 | .59 | $\ll$40.0 | | (b) | | |
| | F | X | | 354.0 | .56 | 54.5 | | (b) | | |
| | G | | X | 420.0 | 2.32 | 96.5 | | 67.0 | | |
| | H | | X | 420.0 | 2.32 | 95.0 | | 65.0 | | |
| | I | X | | 38.5 | 1.35 | 85.5 | | 40.0 | | |
| | J | X | | 38.5 | 1.35 | 77.5 | | 38.0 | | |
| | K | X | | 69.4 | 1.79 | 83.0 | | 54.0 | | |
| | L | X | | 69.4 | 1.79 | 83.5 | | 51.0 | | |
| | M | X | | 69.4 | 1.79 | 76.0 | | 47.0 | | |
| | N | X | | 103.8 | 2.38 | 68.0 | | (c) | | |
| 11 | - | | X | 420.0 | 2.32 | | 97.5 | | 82.0[d] | 80.0[d] |
| 3 | - | | X | 70.9 | 2.06 | | 96.0[d] | | 77.0[d] | 86.0 |
| 14 | - | | X | 69.4 | 1.62 | | 95.0 | | 87.5 | 79.0 |
| 9 | - | | X | 38.5 | 1.40 | | 92.0 | | (c) | 75.0 |
| 10 | - | | X | 38.5 | 1.39 | | 79.0 | | (b) | (b) |
| 5 | - | | X | 38.5 | 1.35 | | 78.0 | | (b) | (b) |
| 5 | - | X | | 38.5 | 1.35 | | 66.0 | | 57.0 | 71.0 |
| 15 | - | | X | 420.0 | 2.00 | | 100.0 | | 91.0[d] | 87.0[d] |
| 5 | - | X | | 69.4 | 1.79 | | 80.0 | | 70.0 | (b) |
| 13 | - | X | | 922.0 | 2.50[d] | | 85.0 | | (c) | (c) |
| Variable area, model 29 | | | X | 38.5 | 1.36 | | 89.0[d] | | 82.0[d] | 68.0 |

[a]Reciprocal of $V_r/P_iT_i$ used in ref. 12.

[b]Beyond burning limit.

[c]Data not obtained.

[d]Estimated value.

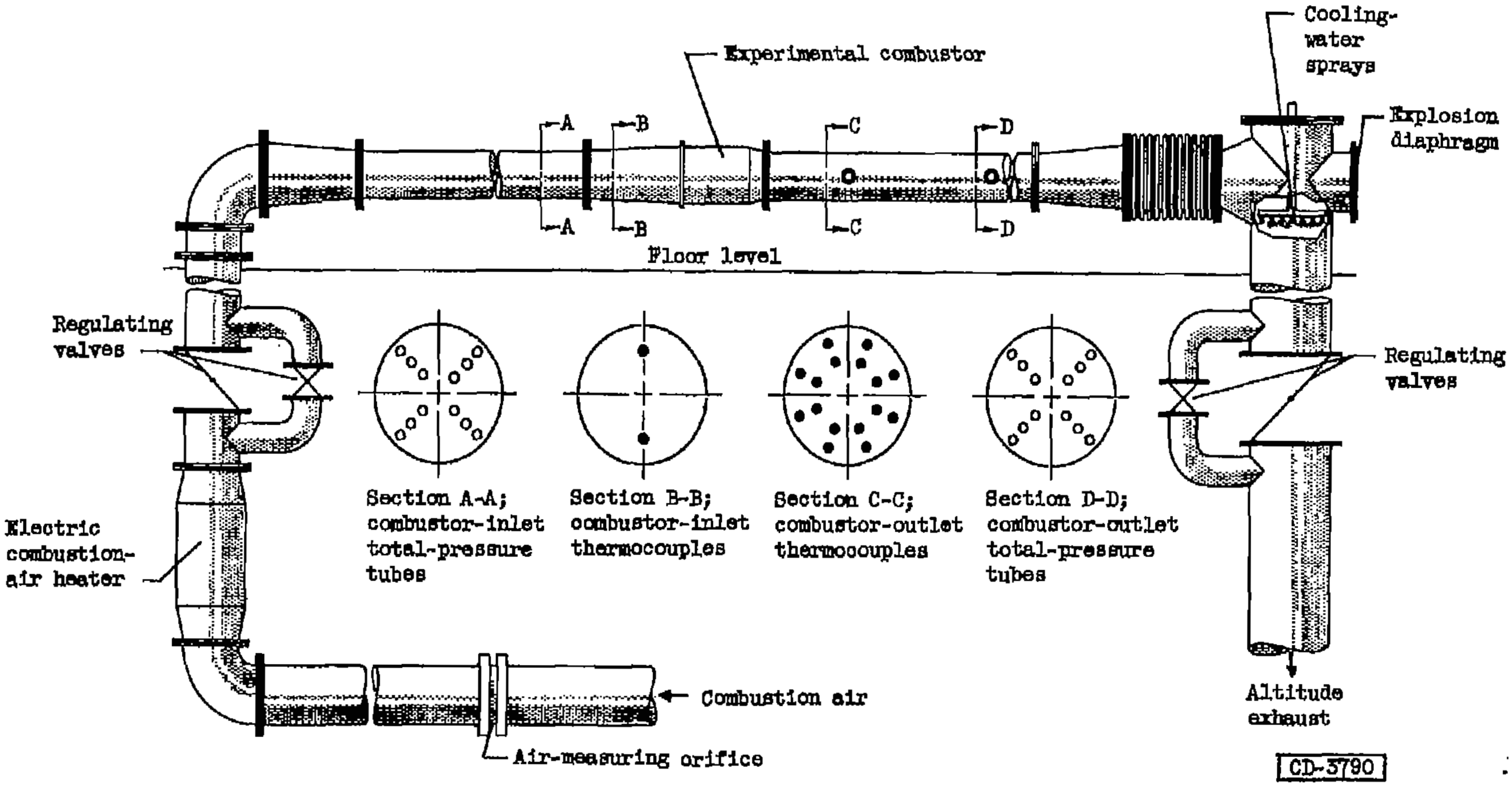


Figure 1. - Experimental-combustor installation, including inlet and outlet ducting and instrumentation stations.

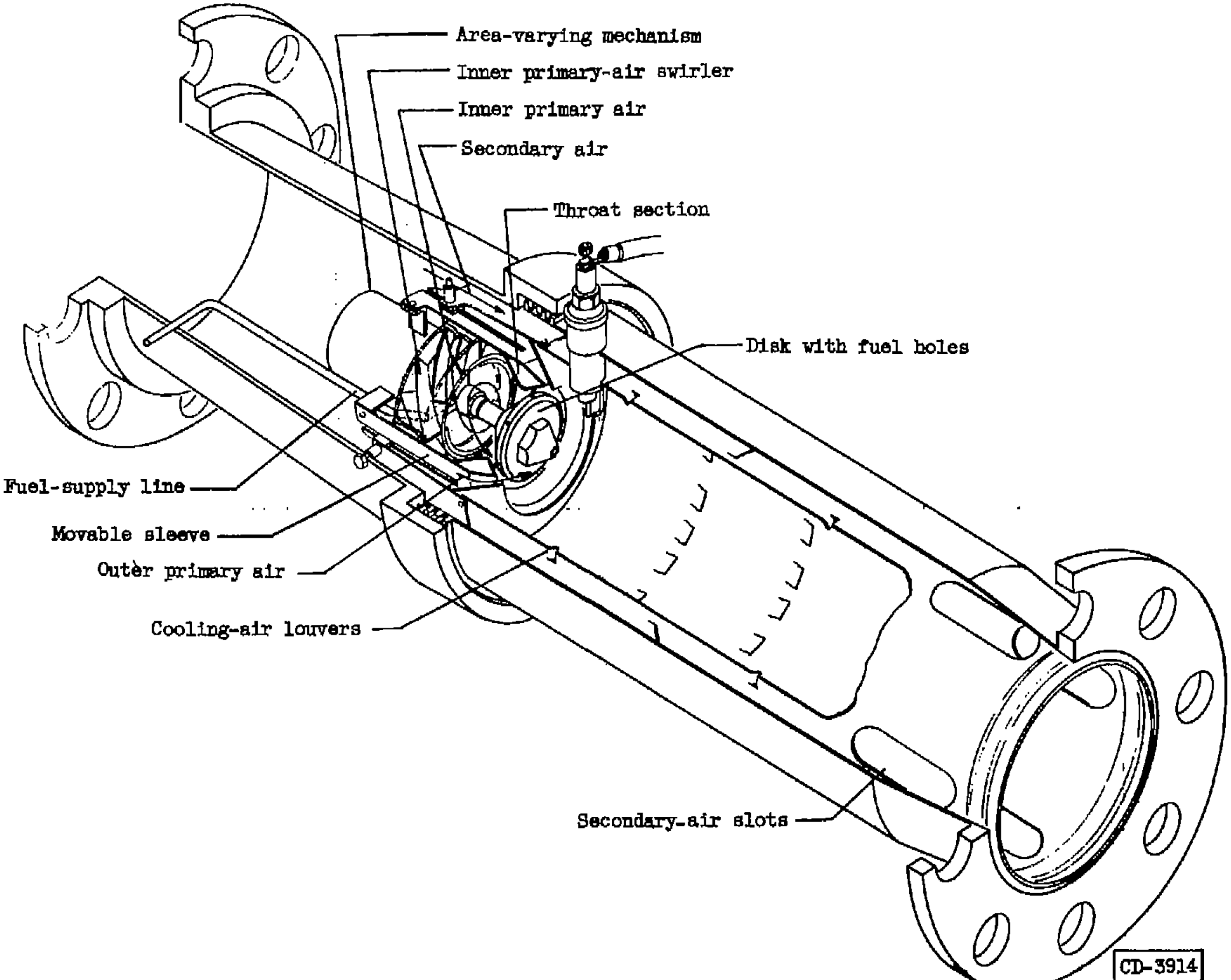


Figure 2. - Basic construction of variable-area combustor.

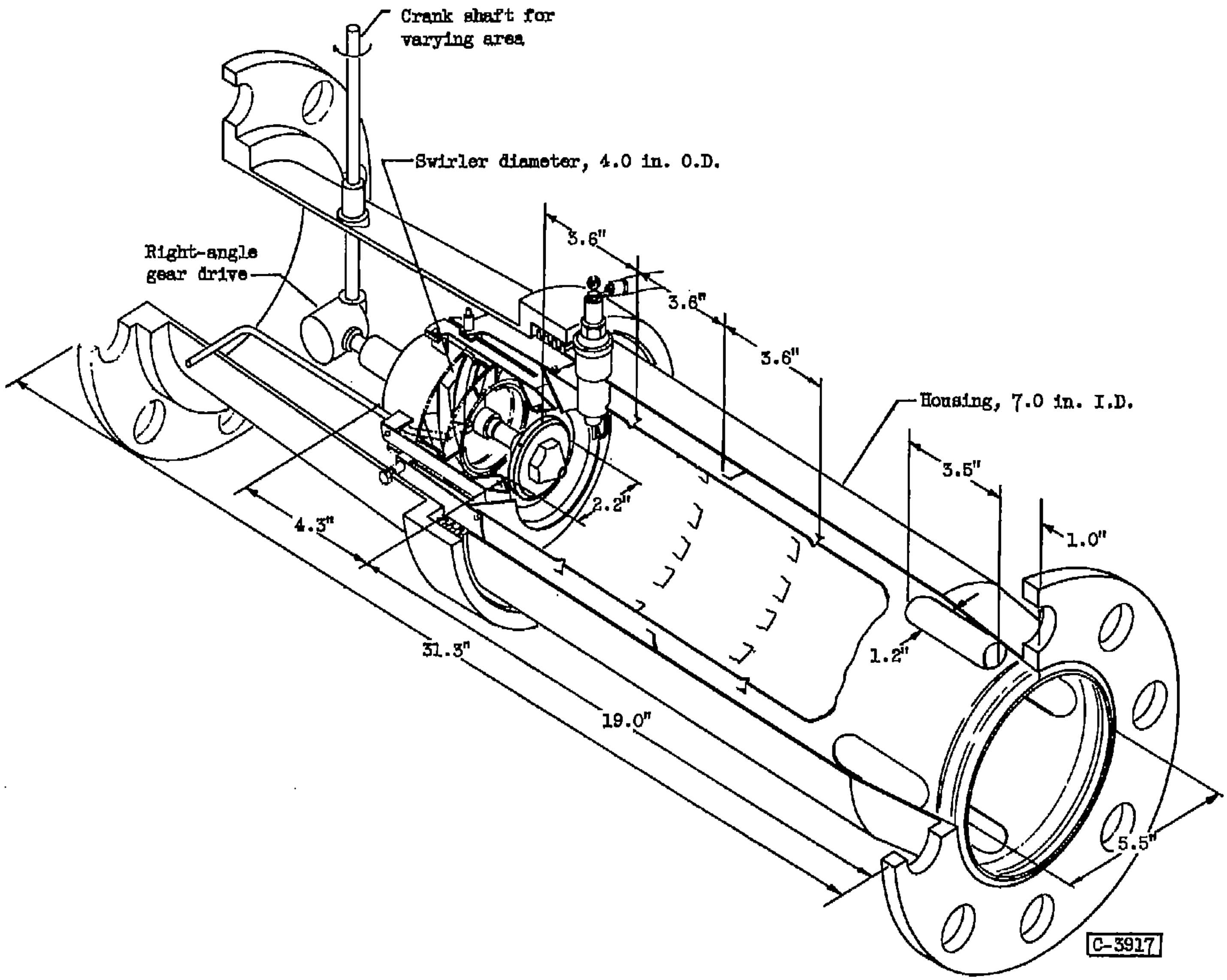


Figure 3. - Mechanical positioner and basic dimensions of variable-area combustors investigated.

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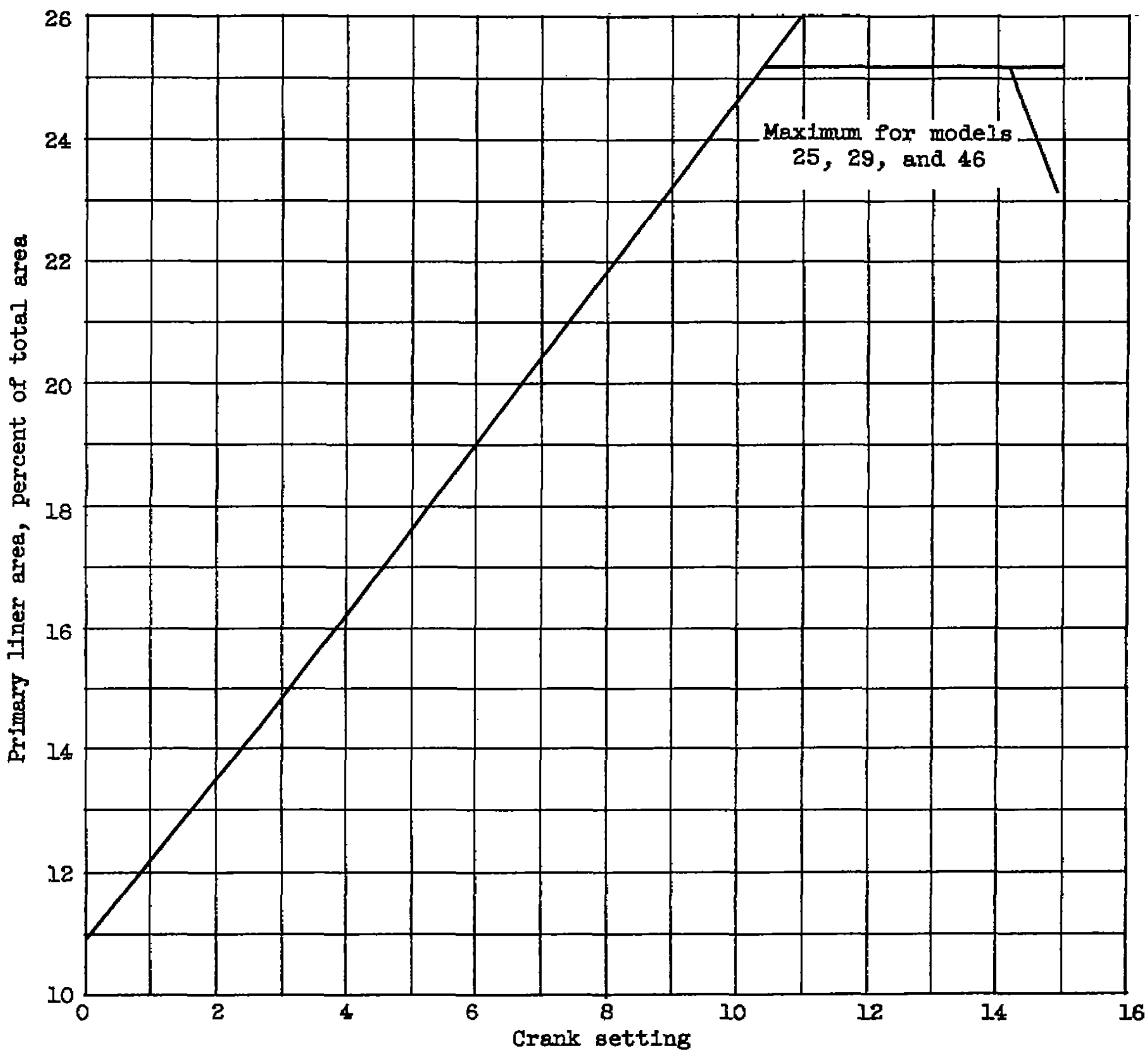
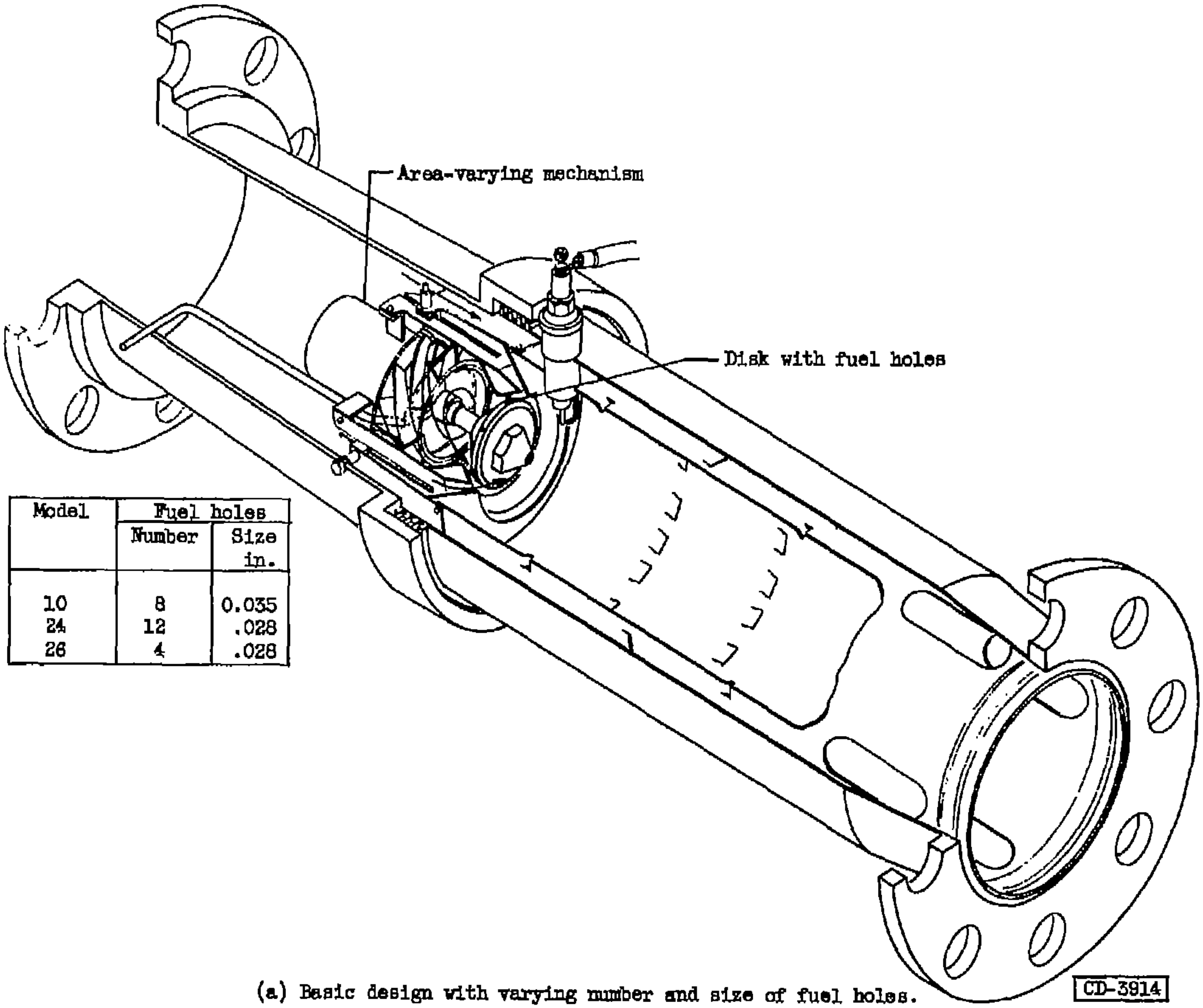


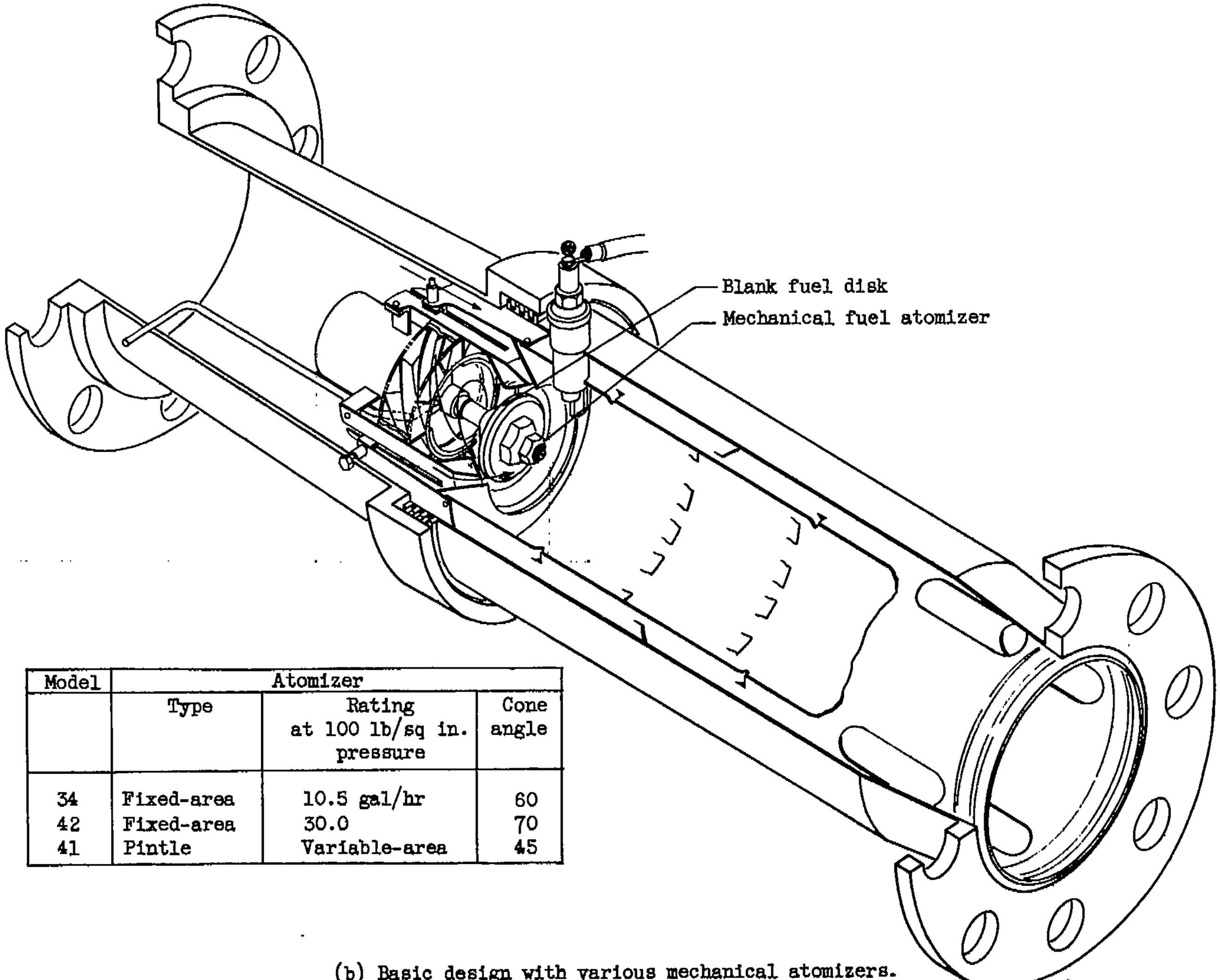

Figure 4. - Variation of primary-air areas with crank setting for variable-area combustor.




| Model | Fuel holes | |
|---|---|---|
| | Number | Size in. |
| 10 | 8 | 0.035 |
| 24 | 12 | .028 |
| 26 | 4 | .028 |

(a) Basic design with varying number and size of fuel holes.

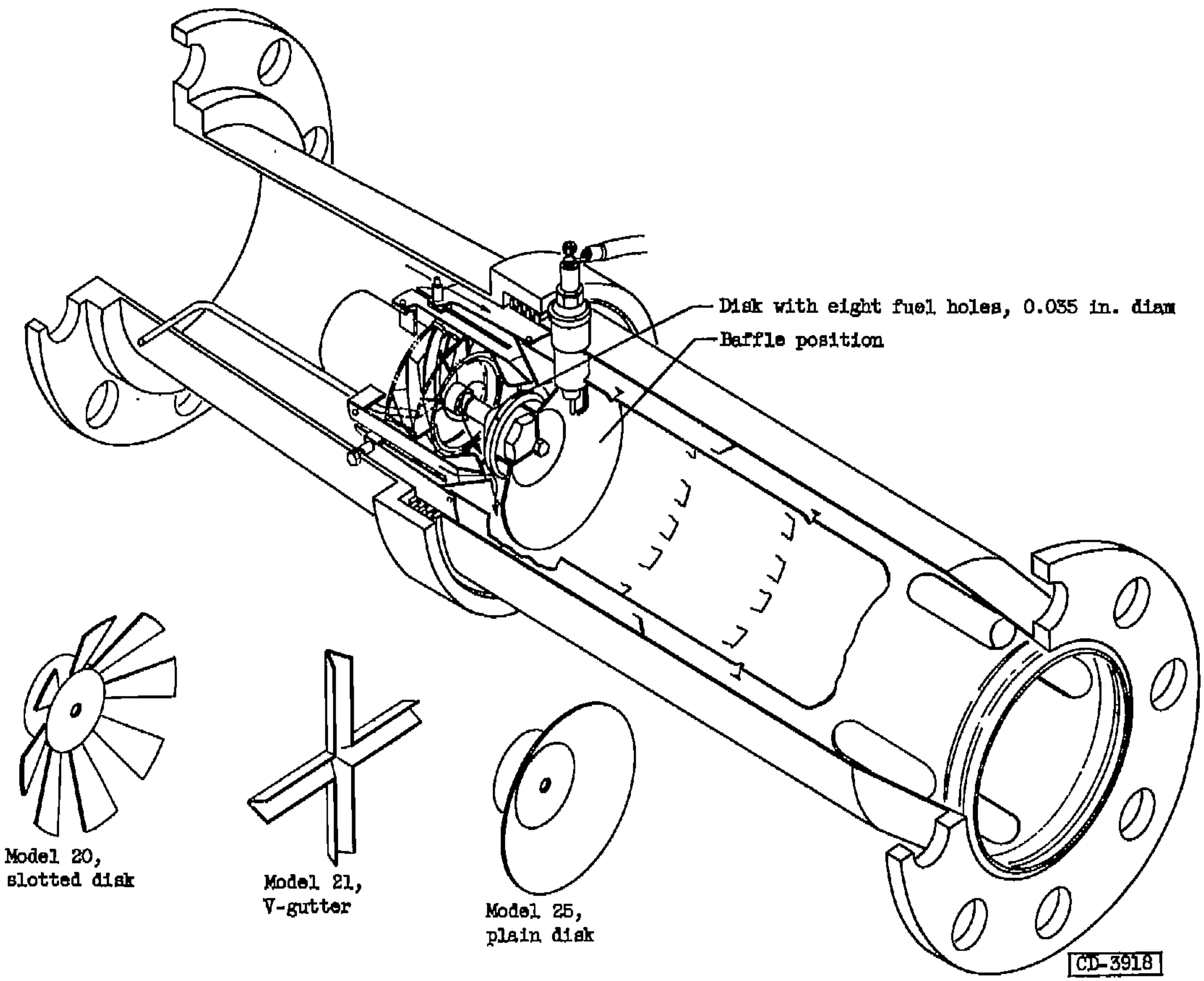
Figure 5. - Experimental variable-area combustor configurations.




| Model | Atomizer | | |
|---|---|---|---|
| | Type | Rating at 100 lb/sq in. pressure | Cone angle |
| 34 | Fixed-area | 10.5 gal/hr | 60 |
| 42 | Fixed-area | 30.0 | 70 |
| 41 | Pintle | Variable-area | 45 |

(b) Basic design with various mechanical atomizers.

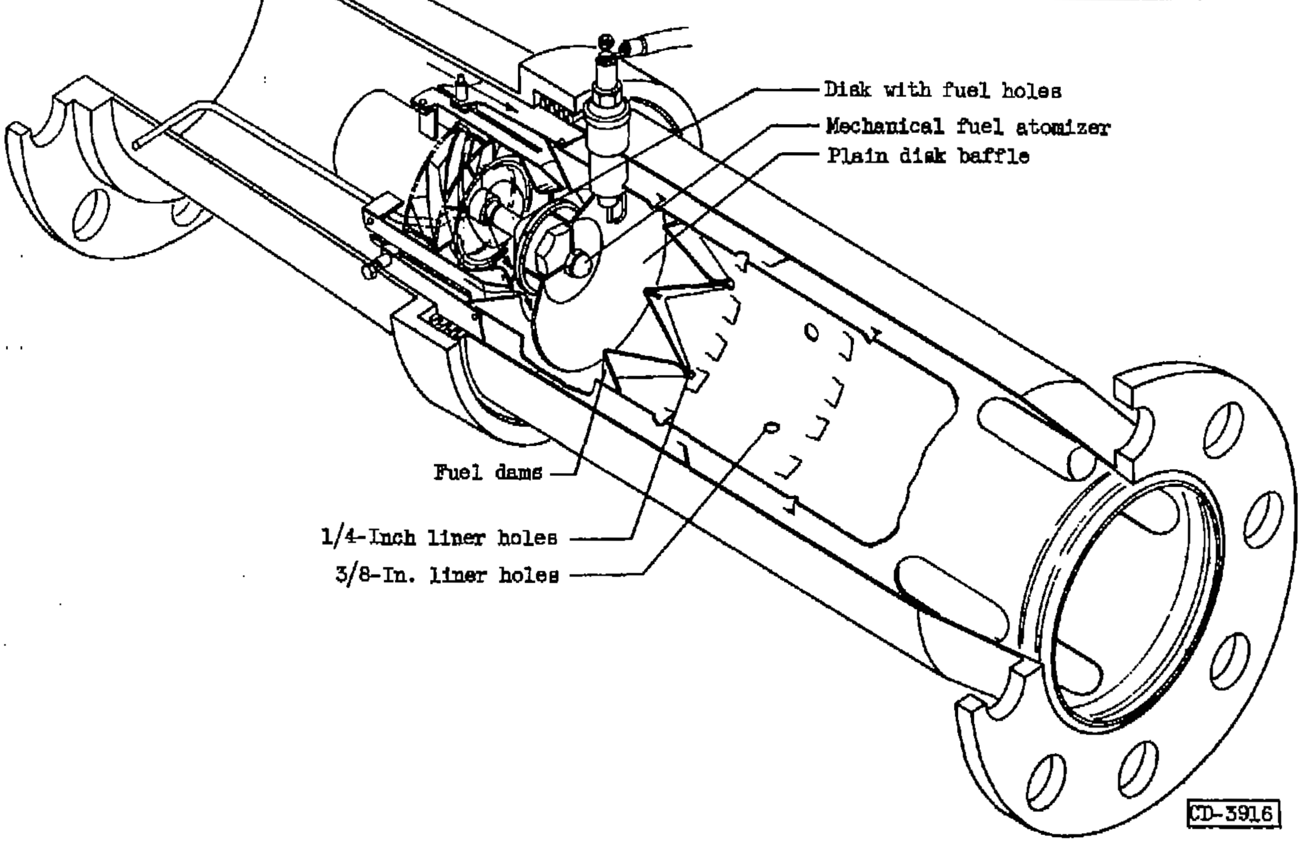
Figure 5. - Continued. Experimental variable-area combustor configurations.




(c) Basic design with various baffles.

Figure 5. - Continued. Experimental variable-area combustor configurations.

| Model | Fuel introduction | |
|---|---|---|
| | Air atomization | Mechanical atomization |
| 29 | Four 0.028-in, fuel holes in disk | 2.0 gal/hr (at 100 lb/sq in.) fixed-area nozzle 60° cone angle |
| 46 | Four 0.0135-in. fuel holes in fuel line, 5/8-in. upstream from blank fuel disk | Variable-area pintle nozzle 45° cone angle |




(d) Combinations of various liner configurations and atomization methods.

Figure 5. - Concluded. Experimental variable-area combustor configurations.

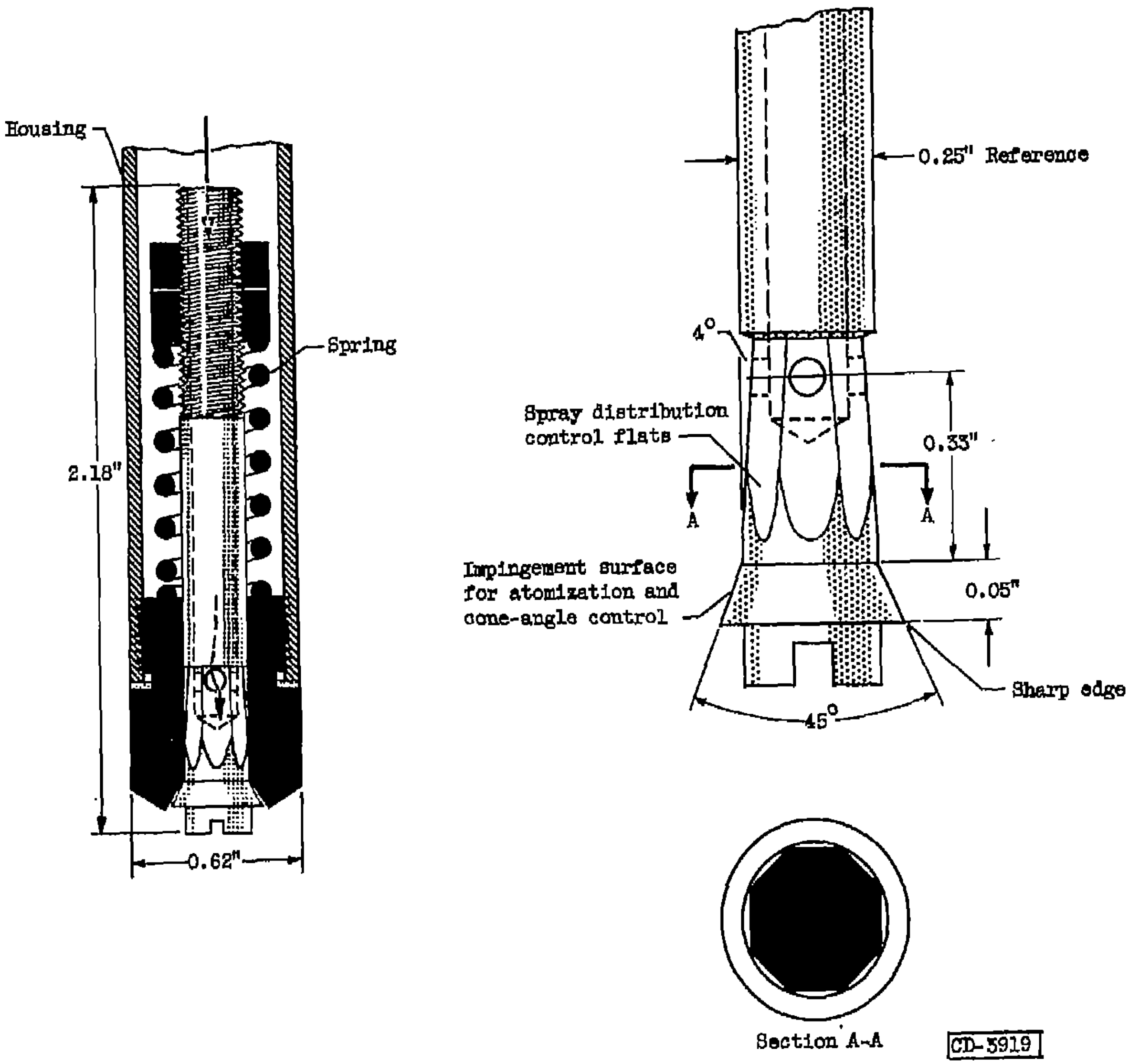
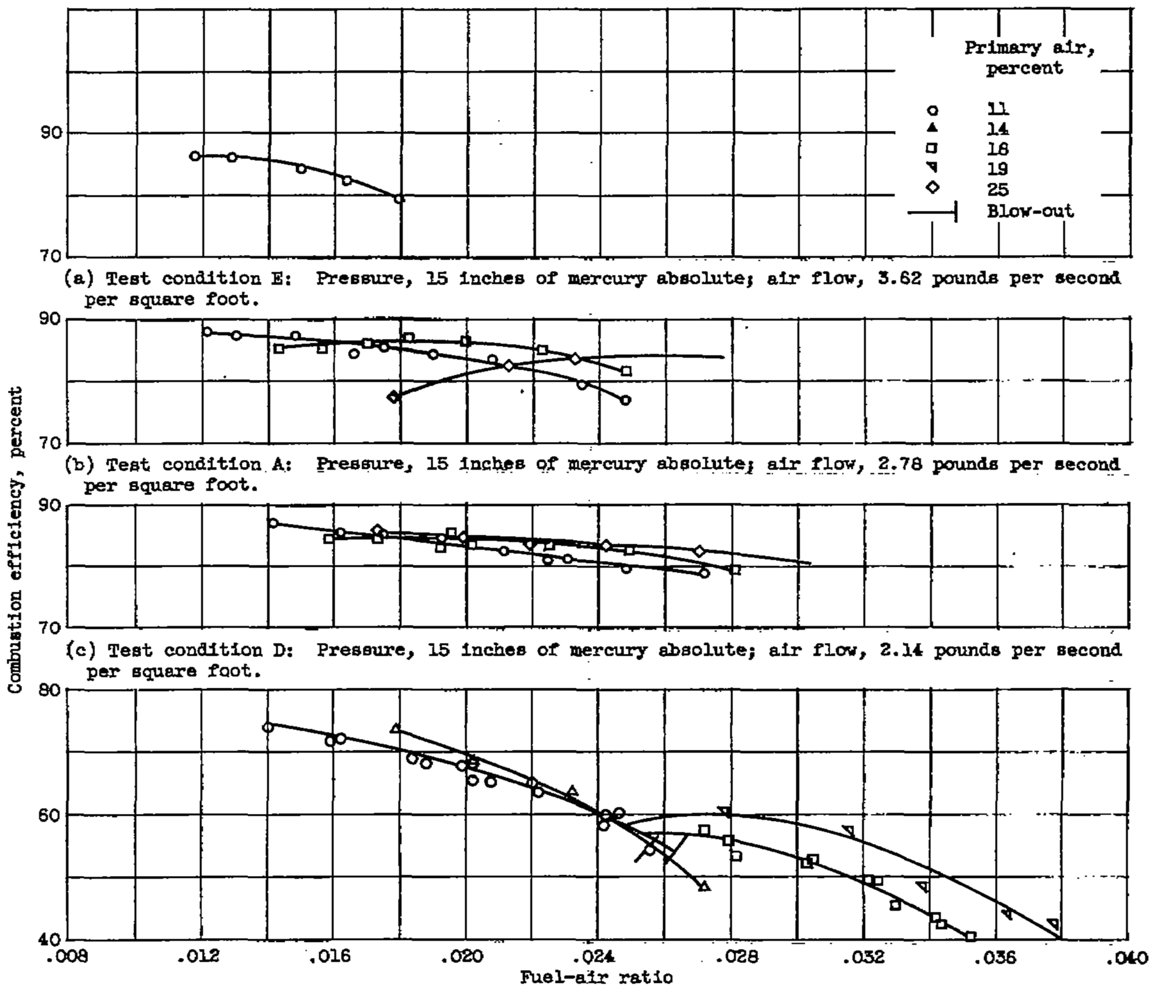
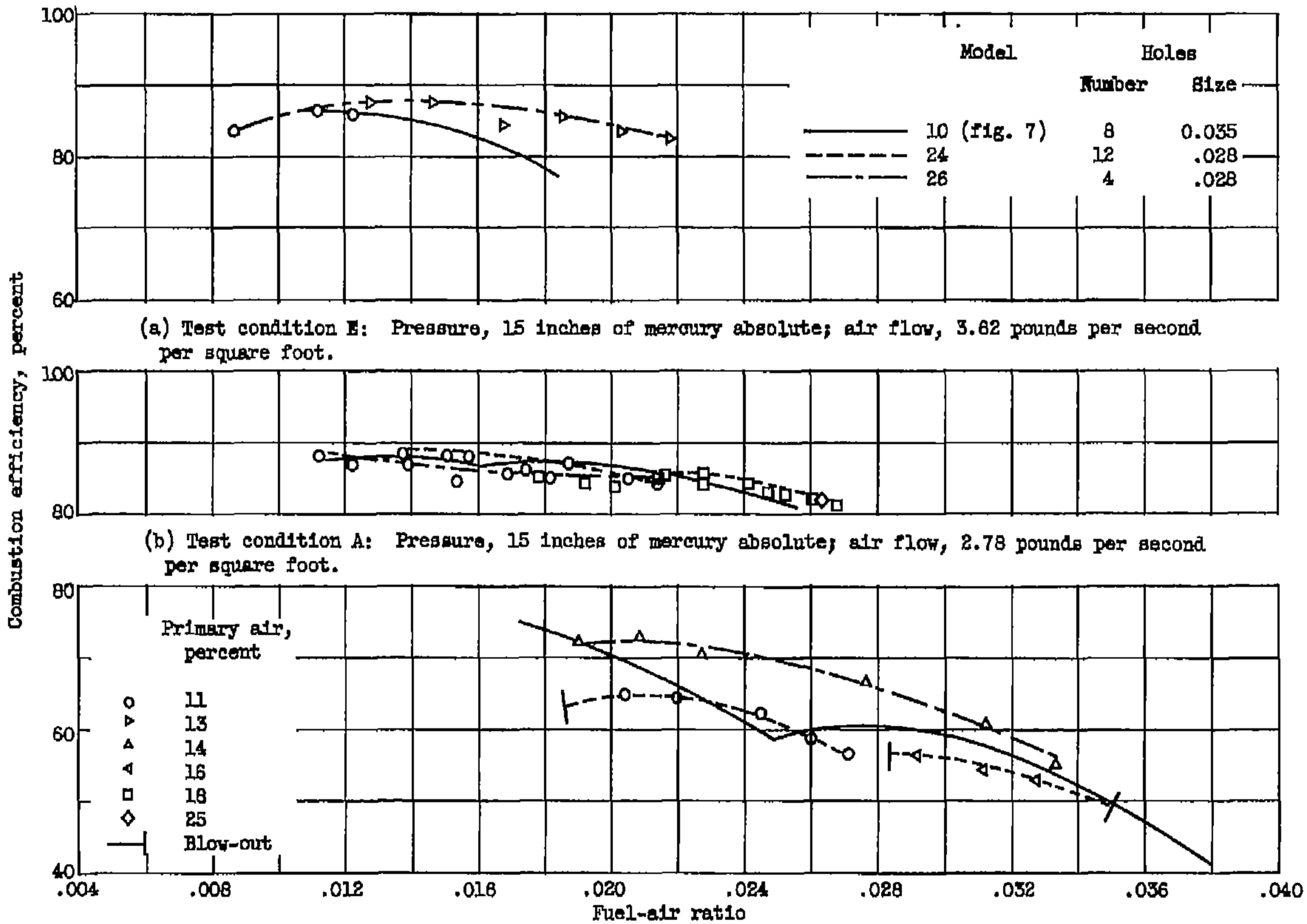



Figure 6. - Variable-area pintle atomizer with spray distribution controlled by eight equal streaks.




(d) Test condition B: Pressure, 8 inches of mercury absolute; air flow, 1.48 pounds per second per square foot.

Figure 7. - Combustion efficiency of model 10, a basic variable-area combustor, showing effect of variable primary-air flow.




(a) Test condition E: Pressure, 15 inches of mercury absolute; air flow, 3.62 pounds per second per square foot.

(b) Test condition A: Pressure, 15 inches of mercury absolute; air flow, 2.78 pounds per second per square foot.

(c) Test condition B: Pressure, 8 inches of mercury absolute; air flow, 1.48 pounds per second per square foot.

Figure 8. - Effect of number of holes in fuel disk on combustion efficiency of variable-area combustor with air atomization.

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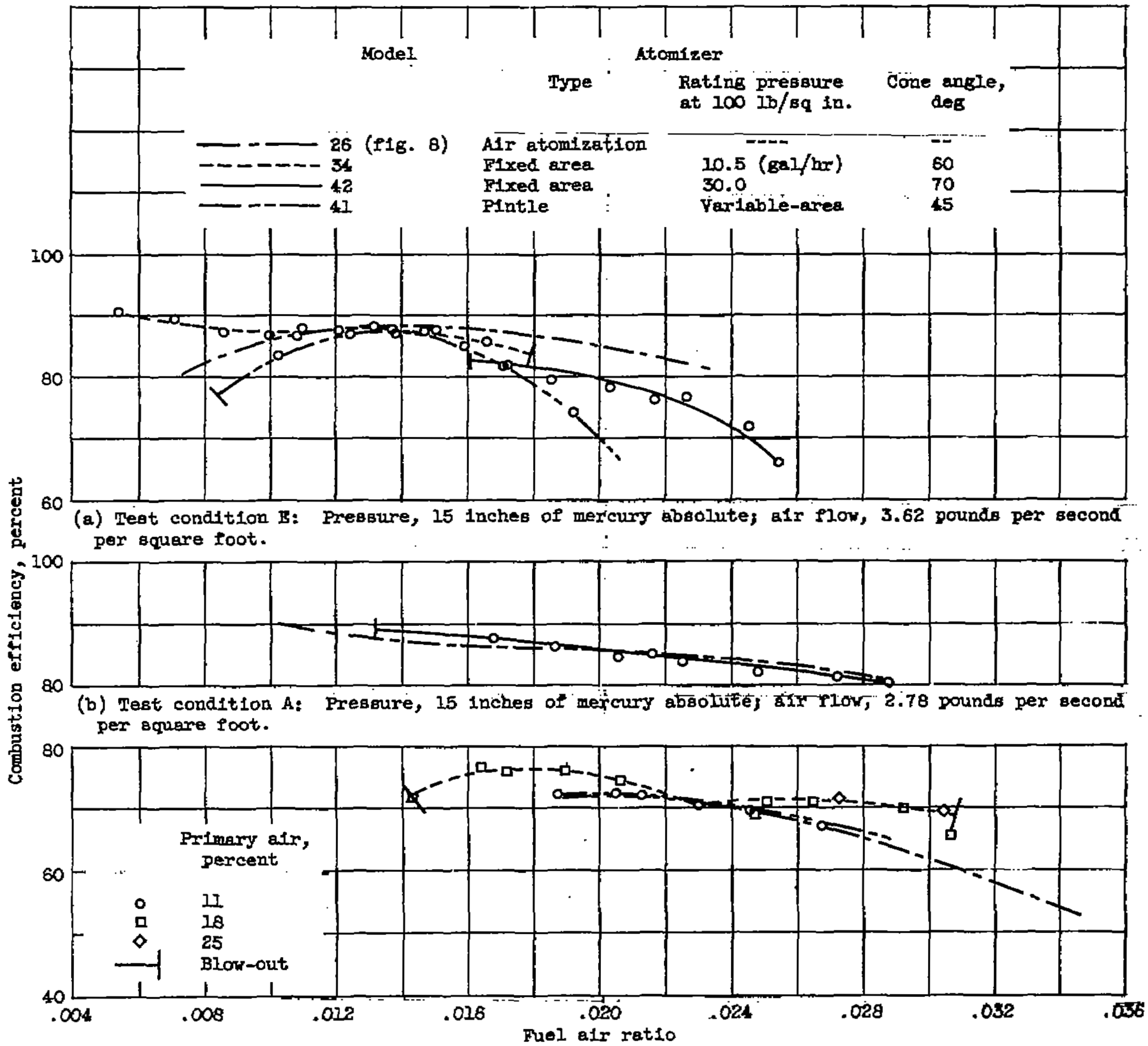


(a) Test condition E: Pressure, 15 inches of mercury absolute; air flow, 3.62 pounds per second per square foot.

(b) Test condition A: Pressure, 15 inches of mercury absolute; air flow, 2.78 pounds per second per square foot.

(c) Test condition B: Pressure, 8 inches of mercury absolute; air flow, 1.48 pounds per second per square foot.

Figure 9. - Combustion efficiency performance of variable-area combustor with mechanical and air atomization.

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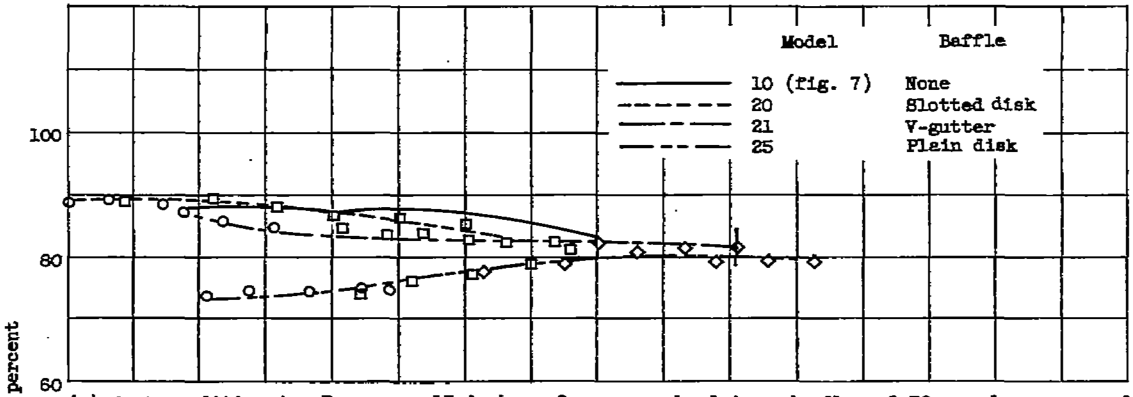
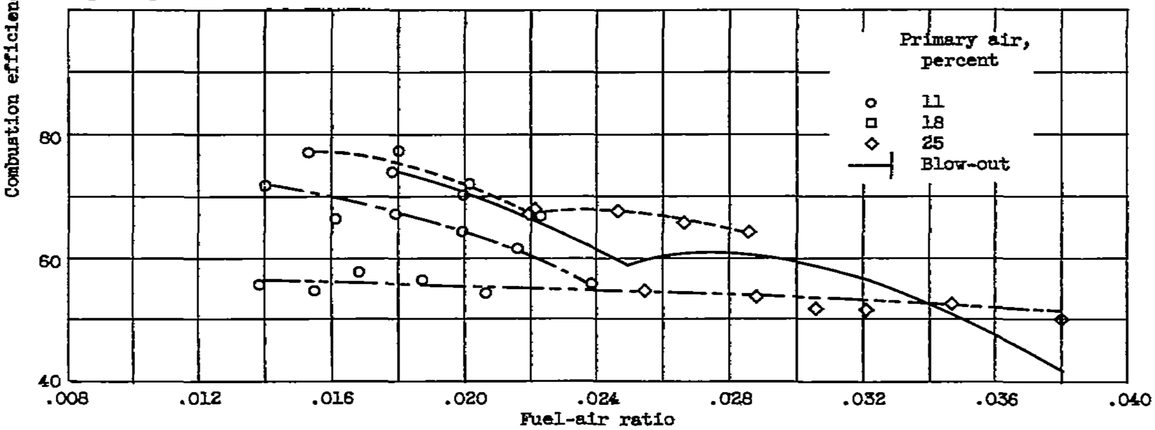
CD-5 back




(a) Test condition A: Pressure, 15 inches of mercury absolute; air flow, 2.78 pounds per second per square foot.




(b) Test condition B: Pressure, 8 inches of mercury absolute; air flow, 1.48 pounds per second per square foot.

Figure 10. - Combustion efficiency of variable-area combustor with several baffles installed; air atomization of fuel.

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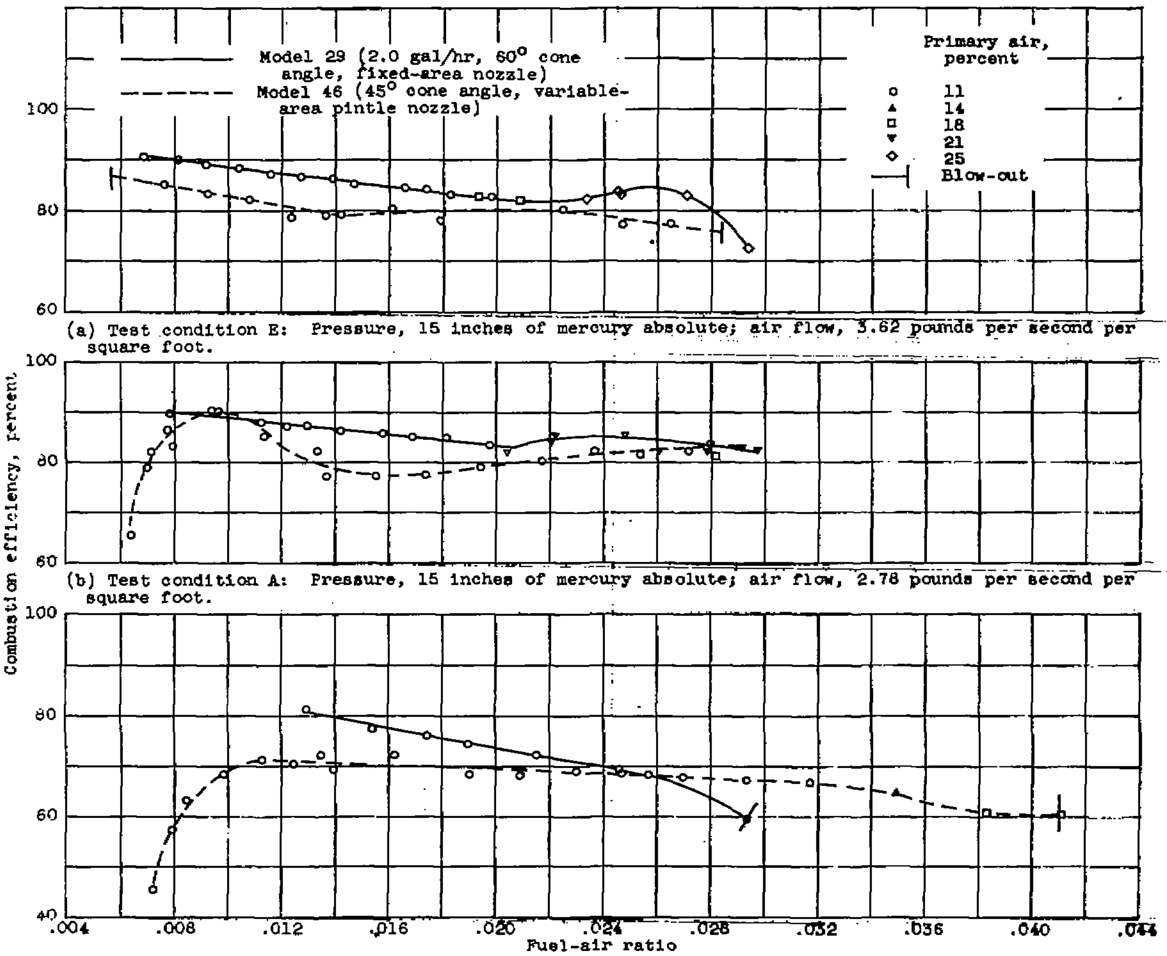


(a) Test condition E: Pressure, 15 inches of mercury absolute; air flow, 3.62 pounds per second per square foot.

(b) Test condition A: Pressure, 15 inches of mercury absolute; air flow, 2.78 pounds per second per square foot.

(c) Test condition B: Pressure, 8 inches of mercury absolute; air flow, 1.48 pounds per second per square foot.

Figure 11. - Performance of best models of variable-area combustor with plain disk baffle, liner holes and fuel dams, and air and mechanical atomization.

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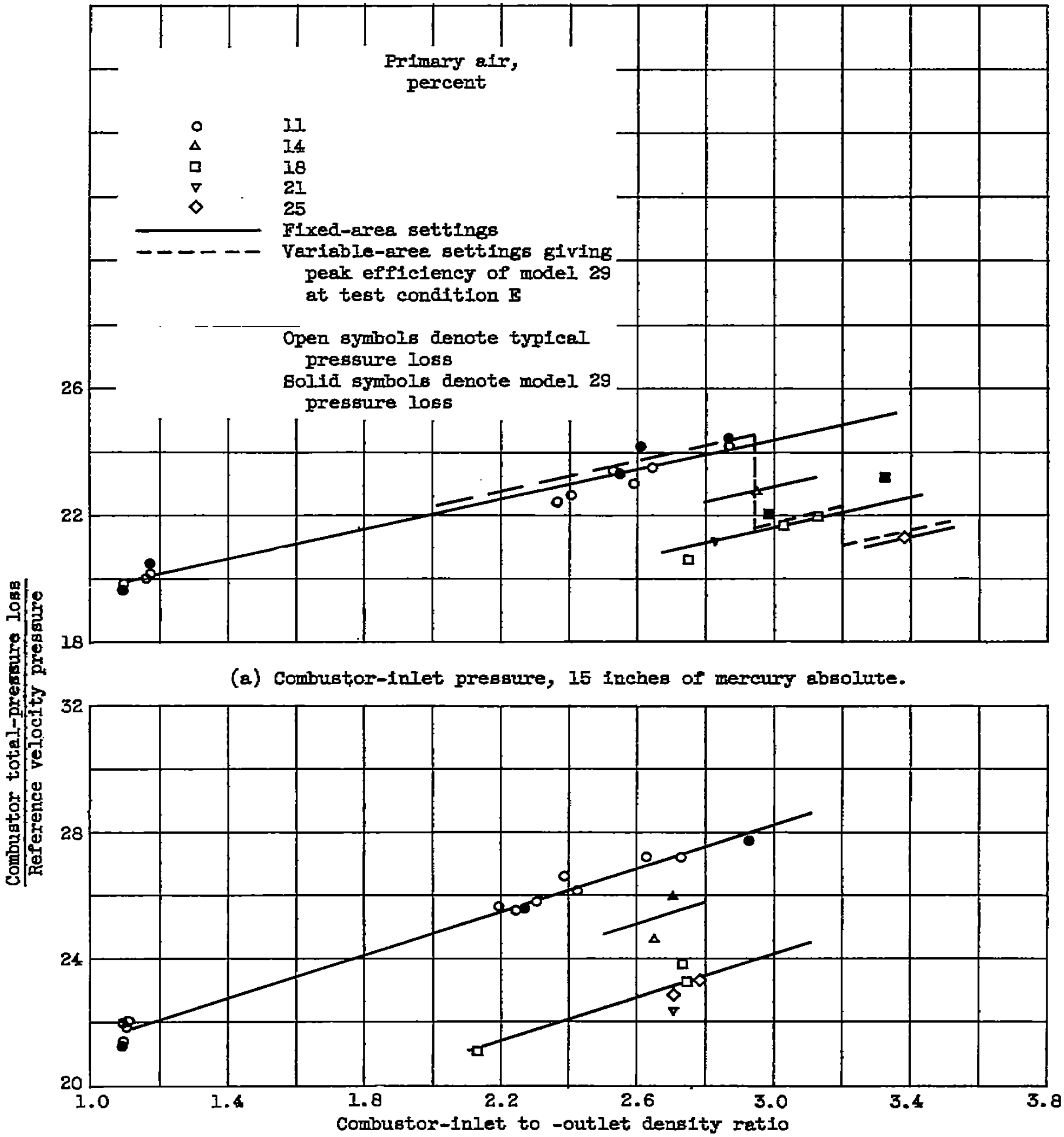


(a) Combustor-inlet pressure, 15 inches of mercury absolute.

(b) Combustor-inlet pressure, 8 inches of mercury absolute.

Figure 12. - Pressure-loss characteristics of several variable-area combustors with plain disk baffles.

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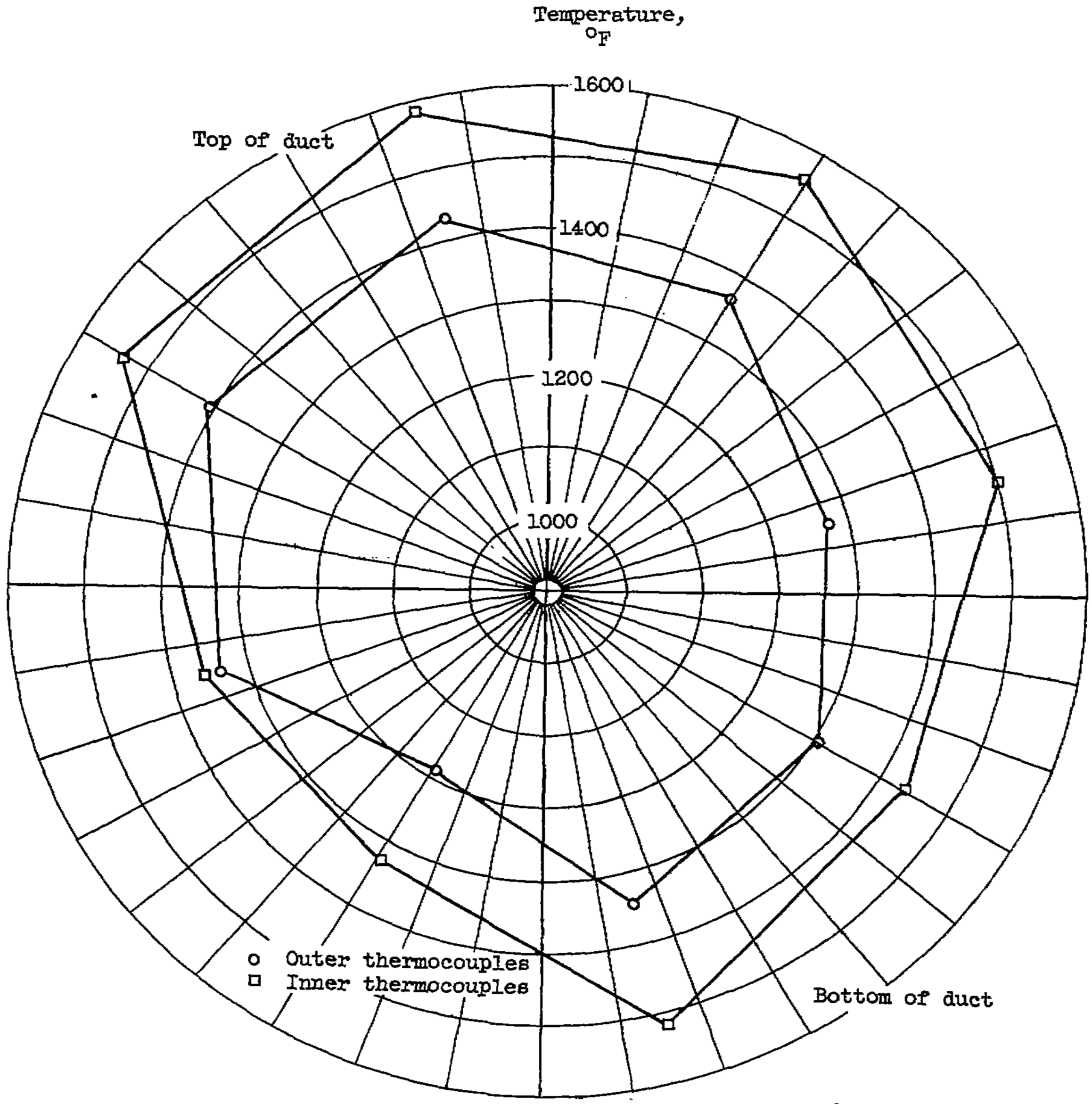


Figure 13. - Typical outlet-temperature profile for variable-area combustor. Model 29. Average temperature, 1420° F.

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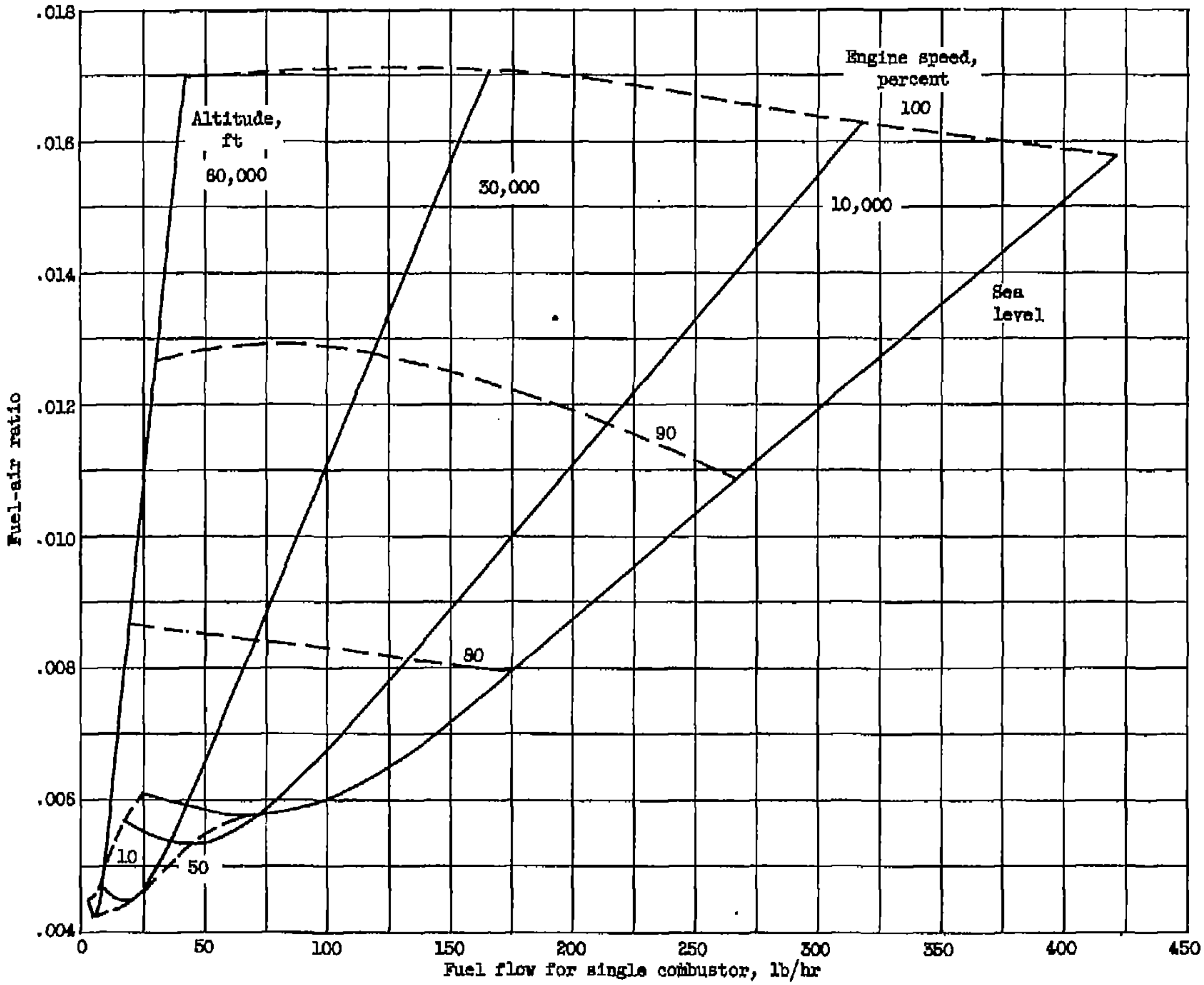


Figure 14. - Variation of fuel-air ratio with fuel flow at several altitudes for typical turbojet engine. Flight Mach number, 0.6; 100-percent combustion efficiency assumed.

[redacted]

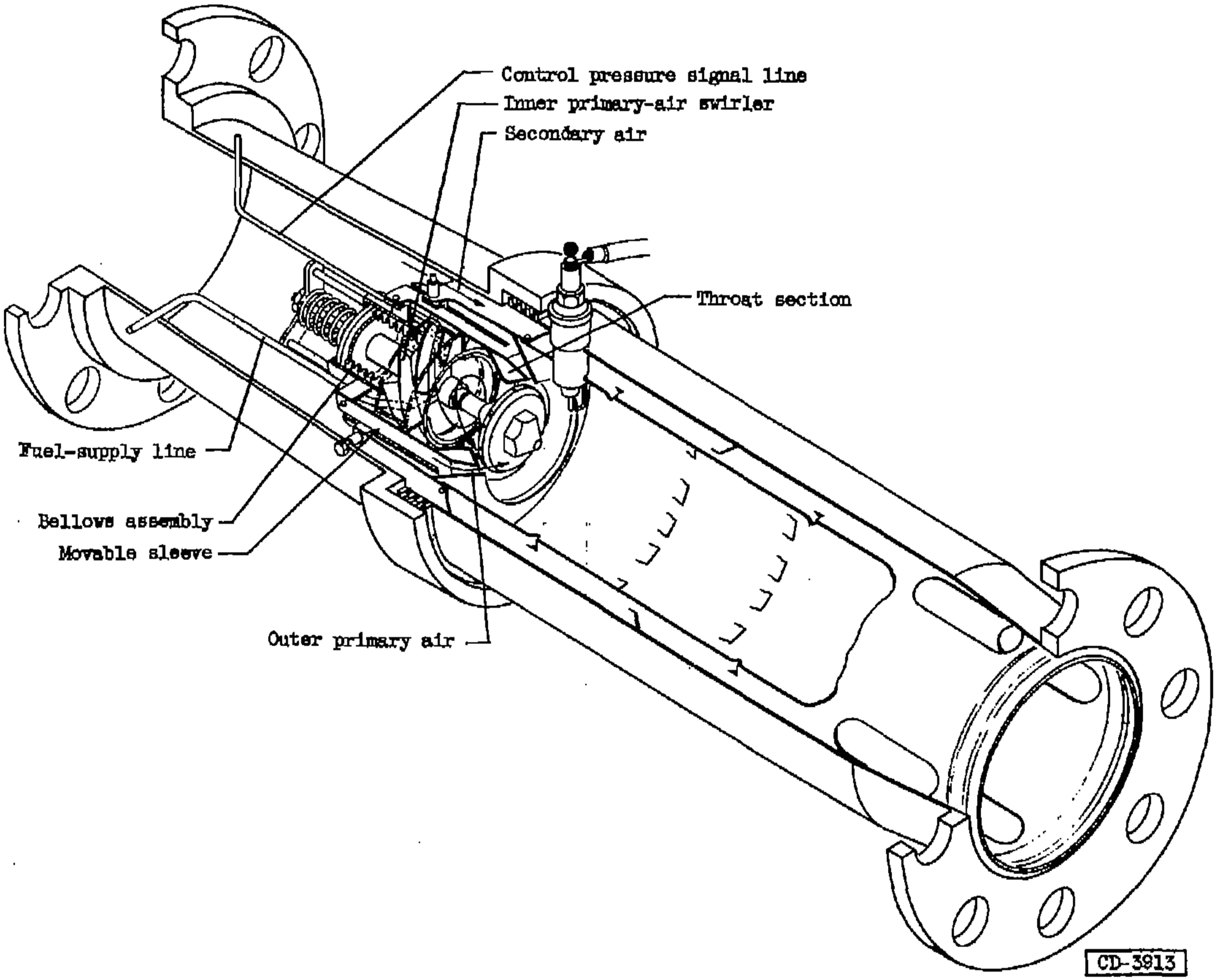


Figure 15. - Variable-area combustor showing one method of controlling primary-air flow.

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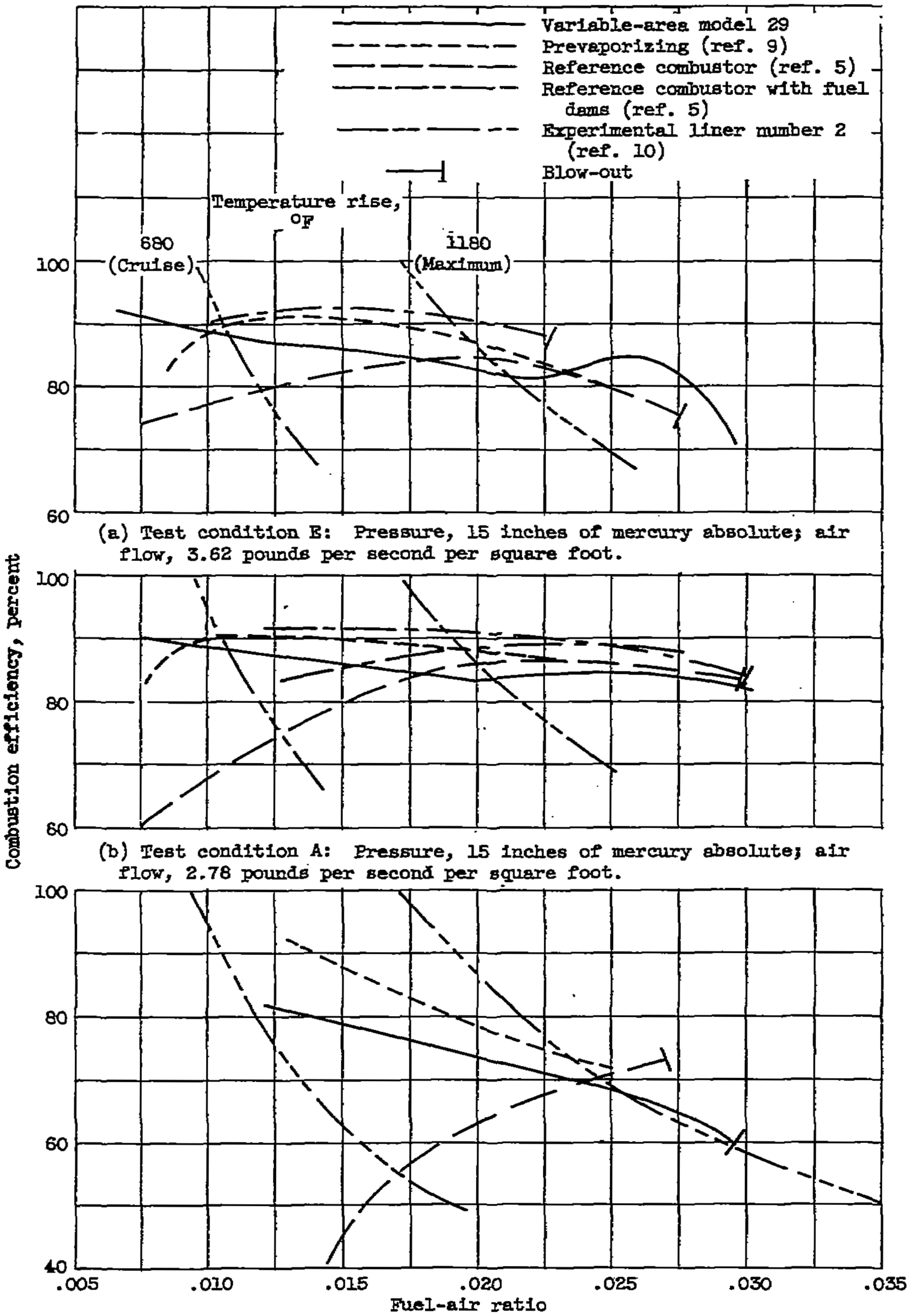
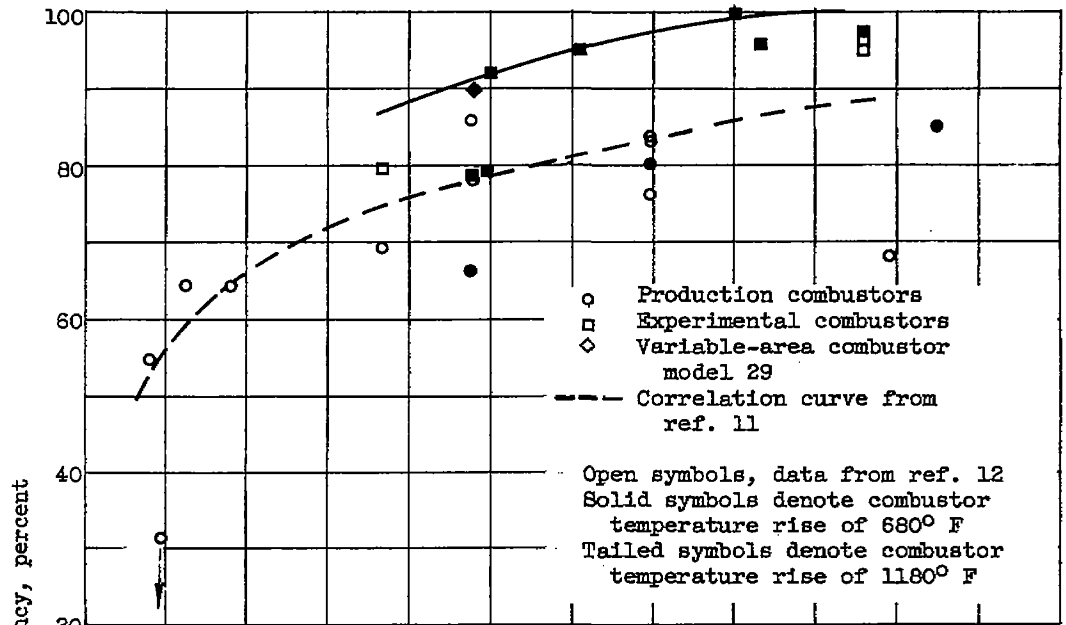



(a) Test condition E: Pressure, 15 inches of mercury absolute; air flow, 3.62 pounds per second per square foot.

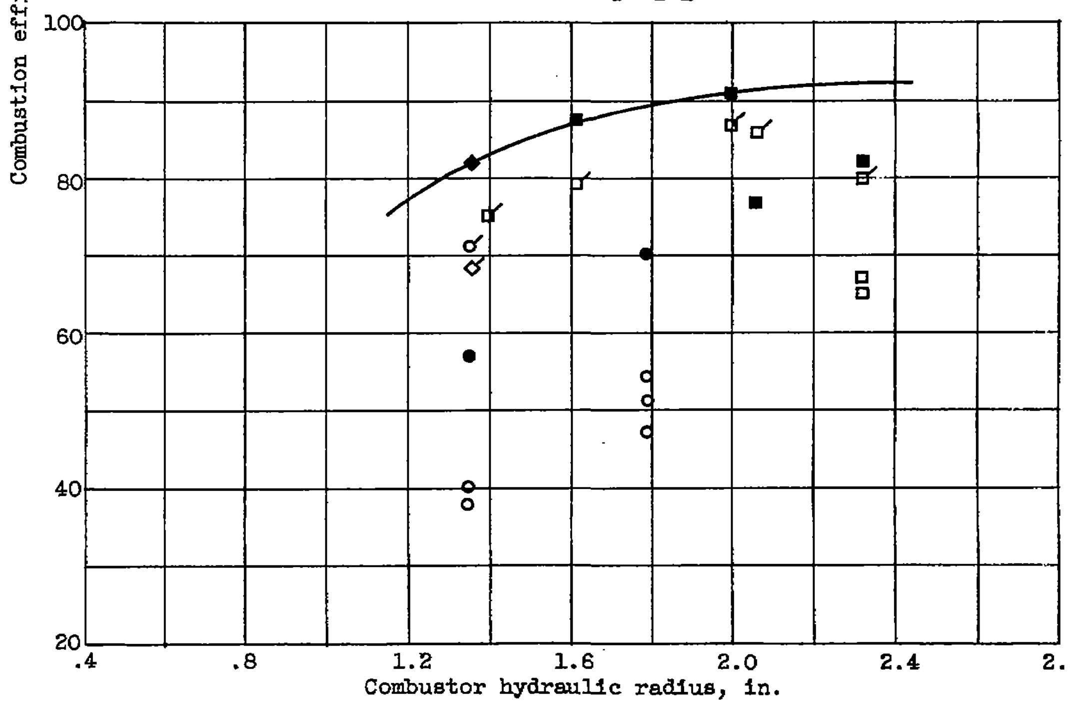
(b) Test condition A: Pressure, 15 inches of mercury absolute; air flow, 2.78 pounds per second per square foot.

(c) Test condition B: Pressure, 8 inches of mercury absolute; air flow, 1.48 pounds per second per square foot.

Figure 16. - Comparison of combustion efficiency performance of several combustor designs in 7-inch-diameter duct.




(a) Combustor parameter, $V_r/P_iT_i = 100\times10^{-6}$.




(b) Combustor parameter, $V_r/P_iT_i = 248\times10^{-6}$.

Figure 17. - Variation of combustion efficiency with combustor hydraulic radius for several production and experimental combustors.

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